MASTER IN COMPUTER SCIENCE

FlowER

Simulation and Visualization of the Patient Flow for Decision Making in a Hospital Emergency Department

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Simulation and Visualization of the Patient Flow for Decision Making in a Hospital Emergency Department

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Abstract

The Canadian health care system needs to deal with serious high wait times problems and overcrowding in the emergency departments. Indeed, it may happen that a patient has to wait up to three hours before being seen by a physician.

This Master's Thesis aims to contribute to a solution by providing a simulation model and a visualization tool. The former gives the ability to catch more information than what is already recorded by the medical staff and allows to answer more questions asked by the management staff of the hospital. The latter, the visualization tool, gives the possibility to have a global view of the patient flow. This flow concerns patients in the emergency department and in the whole hospital. Getting this view allows the managers to have a real time and dynamic feedback of what is going on in the hospital.

Key words: Canadian health care system, emergency department, simulation, visualization, wait time, overcrowding, decision support

Résumé

Le système des soins de santé canadien fait actuellement face à de sérieux problèmes de temps d'attente et de surpopulation dans les départements des urgences. En effet, il n'est pas rare pour un patient de devoir attendre jusqu'à trois heures avant de voir un docteur.

Ce mémoire tente d'apporter des éléments de solution en proposant un modèle de simulation et un outil de visualisation. Le premier permet, notamment, de capturer plus d'informations que ce que le personnel médical n'enregistre actuellement et permet dès lors de répondre à plus de questions que se posent les responsables des hôpitaux. Le second offre quant à lui une vue plus générale du flux de patients présents, non seulement dans le département d'urgence, mais aussi dans tout l'hôpital et permet ainsi aux responsables d'avoir une vue dynamique et en temps réel de ce qu'il se passe dans leur hôpital.

Mots clés: système des soins de santé canadien, département d'urgence, simulation, visualisation, temps d'attente, surpopulation, aide à la décision

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Glossary

Alternate Level of Care (ALC) A patient is declared ALC when she finishes treatment at a given service level and requires lower level services but due to unavailability occupies a higher service level bed.

Ambulance Transfer Of Care (ATOC) The ambulance transfer of care is the formal transfer of responsibilities of an ambulatory patient from the ambulatory staff to the emergency department staff.

Application Programming Interface (API) An application programming interface is intended to be used between different software components in order to allow them to communicate.

Arena Arena is a discrete event simulation environment consisting of module templates, where the user builds her simulation model by placing modules using the intuitive drag-and-drop visual front.

Bottleneck In a system, a bottleneck is a point where the natural flow or the speed is significantly reduced and/or the resources consumption is significantly increased. A bottleneck may result in the complete blockage of a system.

Complex Continuing Care (CCC) Complex Continuing Care is for patients with chronic conditions or a multi-system disease process, such as diabetes, cardiovascular conditions, arthritis and stroke. Patients may be dependent on technology-based continuing or intermittent care or have complex wound management issues. Patients may require specialized geriatric assessment and treatment intervention, and low tolerance rehabilitation services[1].

Clinical Decision Unit (CDU) Clinical Decision Unit is a special department, sometimes part of the emergency department, which acts as the bridge between the hospital and the emergency department. This is for patients with a very small term of care.

Commonwealth Fund The Commonwealth Fund is a private foundation working toward a high performance health system[2].

Canadian Triage and Acuity Scale (CTAS) "*CTAS is one measure of a patient's priority for treatment and an indirect estimator of the symptom severity on arrival to the ED developed by Canadian Association of Emergency Physicians. The urgency or need for ED treatment decreases as CTAS scores increase. The CTAS levels used are 1) resuscitation required, 2) emergent care required, 3) urgent care required, 4) less-urgent care required and 5) non-urgent care required.*" [1]

[1] `http://www.rougevalley.ca/complex-continuing-care`
[2] `http://www.commonwealthfund.org/`

Dashboard "*A dashboard is an interactive GUI that organizes and presents information in a way that is easy to read.*"[3]

Database (DB) In a technical view, this is a collection of data and the structure of data implemented by a computer where those data are saved persistently. A database is generally managed by a database management system (DBMS). In a conceptual view, this is a collection of data which describes an application domain.

eHealth eHealth is "*the transfer of health resources and health care by electronic means. It encompasses three main areas: (1) the delivery of health information, for health professionals and health consumers, through the Internet and telecommunications; (2) using the power of IT and e-commerce to improve public health services, e.g. through the education and training of health workers; (3) the use of e-commerce and e-business practices in health systems*" [2].

Electronic Health Record (EHR) An electronic health record (EHR) is an evolving concept defined as a systematic collection of electronic health information about individual patients or populations. It is a record in digital format that is theoretically capable of being shared across different health care settings. In some cases this sharing can occur by way of network-connected enterprise-wide information systems and other information networks or exchanges. EHRs may include a range of data, including demographics, medical history, medication and allergies, immunization status, laboratory test results, radiology images, vital signs, personal stats like age and weight, and billing information[4].

Emergency Department (ED) An emergency department is a ward within a hospital specialized in providing acute care.

Emergency department crowding (ED crowding) A situation in which the identified need for emergency services outstrips available resources in the ED. This situation occurs in hospital EDs when there are more patients than staffed ED treatment beds and wait times exceed a reasonable period. Crowding typically involves patients being monitored in non treatment areas (eg, hallways) and awaiting ED treatment beds or inpatient beds. Crowding may also involve an inability to appropriately triage patients, with large numbers of patients in the ED waiting area of any triage assessment category. [3]

Emergency Department Information System (EDIS) An emergency department information system is a system consisting of the network of all information technology to support operations, management and decision making in an emergency department.

Expired patient A deceased patient.

[3] `http://searchcio.techtarget.com/definition/dashboard` accessed on the 11/07/2012.
[4] `http://en.wikipedia.org/wiki/Electronic_health_record` accessed on the 07/02/2012.

First In First Out (FIFO) Queueing policy where the first entity entered in the queue, the oldest one, the one which spent the longest time in the queue, will be the first one to leave the queue. For instance, queueing at the post office (assuming a single queue).

Graph "*In mathematics, a graph is an abstract representation of a set of objects where some pairs of the objects are connected by links. The interconnected objects are represented by mathematical abstractions called vertices, and the links that connect some pairs of vertices are called edges. Typically, a graph is depicted in diagrammatic form as a set of dots for the vertices, joined by lines or curves for the edges.*"[5]

Health care system A health care system is an organized plan of health services and its main objective is to provide health care to patients against a fair financial contribution, whatever their location, the time, their ethnic group or social status.

Information and Communications Technology (ICT) "*General term that stresses the role of unified communications and the integration of telecommunications, computers, middleware as well as necessary software, storage- and audio-visual systems, which enable users to create, access, store, transmit, and manipulate information.*" [4]

Java DataBase Connectivity (JDBC) A java database connectivity is a programming interface for java programs to allow them to connect a data source such as a database.

Length of stay (LOS) The length of stay measure how long a patient stays in the hospital for one visit.

Left Without Being Seen (LWBS) "Left Without Being Seen" refers to a patient who left the emergency department before being assessed by a physician or against medical advice.

Long Term of Care (LTC) Long Term of Care department is for patients who need a very long term of care in the hospital.

Nurse "*A nurse is a health care professional who is focused on caring for individuals, families, and communities, ensuring that they attain, maintain, or recover optimal health and functioning. Nurses are capable of assessing, planning, implementing, and evaluating care independently of physicians, and they provide support from basic triage to emergency surgery.*"[6]

Open DataBase Connectivity (ODBC) An open database connectivity is an interface between programs and a database management system.

[5] `http://en.wikipedia.org/wiki/Graph_(mathematics)` accessed on the 11/07/2012.
[6] `http://www.medicalnewstoday.com/articles/147142.php` accessed on the 11/07/2012.

Overcrowding In the emergency department context, overcrowding means that the number of patient is beyond what the medical staff can stand.

Patient A patient is a person wishing to receive medical care.

Patient admission When the patient leaves the emergency department and is admitted into the hospital to receive extra care.

Patient arrival Time when a patient is registered by a nurse.

Patient discharge It is when a patient is considered able to come back home and officially declared as such by a physician.

Physician "*A physician focused on the immediate decision making and action necessary to prevent death or any further disability both in the prehospital setting by directing emergency medical technicians and in the emergency department. The emergency physician provides immediate recognition, evaluation, care, stabilization, and disposition of a generally diversified population of adult and pediatric patients in response to acute illness and injury.*"[7]

Physician Initial Assessment (PIA) The Physician Initial Assessment is the time when a patient has her first contact with a physician.

Radio-Frequency IDentification (RFID) "*Radio-frequency identification (RFID) is the use of a wireless non-contact radio system to transfer data from a tag attached to an object, for the purposes of automatic identification and tracking. Some tags require no battery and are powered by the radio waves used to read them. Others use a local power source. The tag contains electronically stored information which can be read from up to several metres (yards) away. Unlike a bar code, the tag does not need to be within line of sight of the reader and may be embedded in the tracked object*"[8].

Simulation "*A simulation is the imitation of the operation of a realworld process or system over time. Simulation involves the generation of an artificial history of a system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system.*" [5]

(Computer) Simulation model A simulation model running on a computer is a program that simulates the behavior of a particular system.

Triage The Triage is the term derived from the French verb "trier" which means "to sort" or "to choose". This is a process which classifies patients by the type and urgency of their conditions and intends to get the right patient to the right place at the right time with the right care provider. Most of the time, the patient's health is mapped on a scale of illness severity such as the CTAS.

[7] `http://www.medterms.com/script/main/art.asp?articlekey=24810` accessed on the 11/07/2012.

[8] `http://en.wikipedia.org/wiki/Radio-frequency_identification` accessed on the 07/02/2012.

Visualization The visualization is a set of techniques using computer to present visual artifacts on a screen and show different information and/or results.

Wait time The wait time is the time a patient waits in the emergency department. A patient is considered as waiting when she is not receiving care.

What-if analysis "*Simulation analysis in which key quantitative assumptions and computations (underlying a decision, estimate, or project) are changed systematically to assess their effect on the final outcome.*"[9]

World Health Organization (WHO) The World Health Organization "*is the directing and coordinating authority for health within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends.*"[10]

[9] `http://www.businessdictionary.com/definition/sensitivity-analysis.html` accessed on the 07/02/2012.
[10] `http://www.who.int/about/en/` accessed on the 11/07/2012.

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Chapter 1

Introduction

1.1 Problem statement

Information Technology's implementation in the health care domain has increased for many years. However, some problems remain unsolved and a lot of researchers are working in this context. In this Master's Thesis, we will be only focused on the main problems happening in the emergency department, namely the overcrowding and high wait times.

"*Most of ED visits are for less urgent conditions (for example, chronic back pain or minor allergic reactions) or non-urgent conditions (for example, sore throat or menses) based on the Canadian Triage and Acuity Scale (CTAS).*" [1] CTAS level I and II are assessed in priority compared to other patients. Special examination (X-rays), specialist assessment or waiting for an available bed (sometimes longer than 24 hours [6]) can significantly impact the wait time considering the unavailability of resources. Because of the high level of patient illness variety and the (almost) unpredictable arrival behavior of patients coming in the emergency department, some of them have to wait more than three hours before being seen by a nurse or a physician.

This problem is an important matter due to the growing population and the IT may be a part of the solution.

To show the importance of the overcrowding, the main impacts can be that the average time before a patient is seen by a physician is high but also that the hospital crew can be overextended, influencing the quality of the care provided.

1.2 Approach and methodology

In order to have an impact on high waiting times and the overcrowding in the emergency departments, we decided to build a simulation model and a visualization tool.

1.2.1 Simulation

"*A* simulation *is the* imitation *of the operation of a real world process or system* over time. *Simulation involves the generation of an* artificial *history of a system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system.*" [5]

Simulations are increasingly used in health care in order to study the behavior of a system and the interactions between its components on the basis of concrete data, of concrete systems.

More precisely, our simulation model intends to encapsulate at the same time the management issues of the patients, the medical staff and the medical equipment (X-Ray, etc). Furthermore, we want it to be able to handle problems of internal decisions, providing a tool for decision support to answer questions like *is hiring an additional nurse for night shift a good option?* In particular, we used the data provided from the *Rouge Valley Health System* to simulate their particular patient flow.

1.2.2 Visualization

In addition to the simulation model, we developed a visualization tool.

Visualization provides interactive user interfaces to organize and present the increasing amount of data in a way that is easy to read.

We wanted our visualization tool to be different of the classical dashboard view in order to propose to the hospital managers a *real and dynamic overview* of the patient flow in the emergency department but also in the whole hospital. Therefore, we developed the visualization tool which shows a *graph view* of all the key points of the hospital process, and which offers some statistics in relation to these key points.

1.3 Purpose of this Master's Thesis

We said that high wait times and overcrowding in the emergency department are important and challenging issues. The purpose of this Master's Thesis is to propose two ways to tackle this problem by (1) using a simulation tool and model to provide a better prediction of what will happen in the department and process "what-if analysis", (2) developing a visualization tool allowing the management staff to fully trace the patient flow through the emergency department and the hospital.

These two objectives will take place in the context of one of the *Rouge Valley Health System* hospitals in Toronto, our partner in this project with the participation of its Chief Information Officer (CIO), Mr. Thodoros Topaloglou.

In consequence of this partnership, a third objective will be to (3) analyze and model the real data received from the hospital.

1.4 Document structure

The structure of this Master's Thesis will be the following:

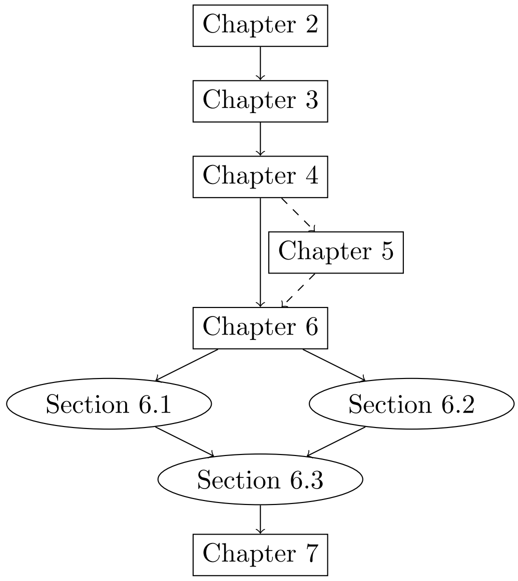

Figure 1.1: Structure of this Master's Thesis

- *Chapter 2:* Context definition focused on the health care system.
- *Chapter 3:* Context definition focused on the hospitals.
- *Chapter 4:* Methodology of our approach and detailed problem specification.
- *Chapter 5:* Simulation basic concepts, containing theoretical information in order to fully understand the following chapter. Chapter 5 is an optional chapter for readers with a simulation background.
- *Chapter 6:* Contributions and explanations of our work. This chapter is divided into three sections:
  - *Section 6.1:* The simulation model section contains information about the simulation model created and the results obtained.
  - *Section 6.2:* The visualization tool section explains the visualization software developed.
  - *Section 6.3:* This section presents all the processes we have done on the data received.
- *Chapter 7:* This last chapter contains the conclusion of our work as well as evaluations and lessons learned.

To represent the reading flow of this Master's Thesis, Figure 1.1 corresponds to the presented document structure. The dashed arrows are the optional path for the reader.

1.5 IBM Cascon

The work presented in this thesis has been selected for presentation at the *IBM Centre for Advanced Studies CONference (CASCON) 2011*[1]. It was presented in the form of a poster, that we prepared and submitted during our internship. This poster can be found in Appendix D. The conference took place from the 7th of November to the 10th of November at the Markham Conference Centre, in Toronto. This conference mainly concerned the implication of the IT in the health care domain. It is open to the academia and research public but also to the industry and general public. It aims at gathering people around the table to share experience and create networks. The poster presentation is part of the *Technology Showcase* which is made of conferences, technological presentation and a posters exposition.

[1] https://www-927.ibm.com/ibm/cas/cascon/

Chapter 2

The Health Care system

The health care domain (or system) is one of the most important in our society. It is an organized plan of health services and its main objective is to provide health care to patients against a fair financial contribution, whatever their location, the time, their ethnic group or social status.

The World Health Organization (WHO)[1] defines it as follows: "*A health system consists of all organizations, people and actions whose primary intent is to promote, restore or maintain health. This includes efforts to influence determinants of health as well as more direct health-improving activities. A health system is therefore more than the pyramid of publicly owned facilities that deliver personal health services. It includes, for example, a mother caring for a sick child at home; private providers; behavior change programs; vector-control campaigns; health insurance organizations; occupational health and safety legislation. It includes inter-sectoral action by health staff, for example, encouraging the ministry of education to promote female education, a well known determinant of better health.*" [7]

Health care systems vary from one country to another as expectations can be driven by the government, by external corporations or both of them. These are institutions which define the policies of the health care system. It concerns the number of hospitals per area as well as the total number of doctors or the quality needs of the care.

The emergence of computers and Computer Science involved major changes in the whole industry. It includes the health care domain where the utilization of computers, information systems, networks and many more is growing prodigiously. Health care providers, at the same level of big companies, are in deep need of new technologies to have an access to more and more information about their patients' health to always offer improved care.

Information and Communication Technologies (ICT) are now mature enough to offer to the health care domain a whole range of services, grouped under the name of *eHealth* services. For instance, eHealth includes services such as medical imaging, Electronic Medical Records (EMR), patient and/or clinician web portals, learning platform, etc.

[1] `http://www.who.int/en/`

This chapter describes in more detail the composition of the health care system in developed countries. It does not only include the hospitals management but also lots of other care providers. We will describe the different levels of care delivery, from the family doctor to the health insurance and the hospitals, and the different challenges to face with.

Afterwards, we will give a definition of eHealth and the dimensions of its contributions in the health care domain. We will see that it has a very high importance and is more and more present in the research domain, especially for universities.

2.1 Health Care

Health care is one of the most important industries considering the fact that everybody has, one time or another, to get in touch with the health care industry to receive care. It starts with the birth generally in a hospital, continues through regular visits to a doctor for a simple cold or scratches and may finish in a geriatric care center. There is no exception, everybody comes into contact with the health care system and considering, the size of the population and the numerous medical problems we may encounter, the health care system must have a solid foundation to provide high quality health care products or services, faces day by day new challenges and always innovates with fresh approaches.

The health care system generally embraces the following elements [8]:

1. *"Personal health care services for individuals and families, available at hospitals, clinics, neighborhood centers, and similar agencies, in physicians' offices, and in the clients' own homes.*
2. *The public health services needed to maintain a healthy environment, such as control of water and food supplies, regulation of drugs, and safety regulations intended to protect a given population.*
3. *Teaching and research activities related to the prevention, detection, and treatment of disease.*
4. *Third party (health insurance) coverage of system services."*

We will further describe most of these elements in the following section.

2.1.1 Care delivery

The health care system is not one big and monolithic institution. It is composed of many institutions having their specific goals in terms of care providing. Such institutions are named *medical facilities*. A medical facility is a place where medicine is practiced regularly. It includes family doctors' offices and goes to large hospitals with sophisticated emergency rooms. As we said, a medical facility may be owned and operated by a for-profit business, a non-profit organization or by a government.

Everybody knows the main medical facilities as everybody has already resorted to these or heard about it:

- Hospital: "*a health care facility that provides inpatient beds, continuous nursing services, and an organized medical staff*" [9] (find detailed information about hospitals in chapter 3).

- Health care center: including clinics, doctor's offices, urgent care centers and ambulatory surgery centers, are the first places where people go to when they are looking for care.

- Medical nursing home: including residential treatment centers and geriatric care facilities, are health care institutions which are in charge of short-term or long-term medical care, potentially specialized care.

- Pharmacies and drug stores: places whose principal activity is to prepare and/or dispense prescription or nonprescription drugs and medicines. Some may be found in a hospital or clinic.

- Medical laboratory and research: a medical laboratory or clinical laboratory is a laboratory where tests are done in order to get information about the health of a patient. There are two main types of labs: (1) hospital laboratories which are attached to a hospital, and perform tests on the patients; (2) private or community laboratories which receive samples in order to perform analyzes and deliver results.

  A medical research facility is where basic or applied research is conducted to help the body of knowledge in the field of medicine.

All these medical facilities are scattered in what is called *the six levels of health care*. Such a division of the modern health care may vary from a country to another but there appears that it is the more common way to divide the health care system as it fits the largest number of them and has been defined in this way by the Department of Health and Human Services in the United States [8].

Primary care is the very first contact of consultation for a patient entering in the health care system. "*Its major task is the early detection and prevention of disease and the maintenance of health. This level of care also encompasses the routine care of individuals with common health problems and chronic illnesses that can be managed in the home or through periodic visits to an outpatient facility. Providers of care at the primary level include family members as well as the professionals and paraprofessionals who staff community and neighborhood health centers, hospital outpatient departments, physicians' offices, industrial health units, and school and college health units.*" [8]

Secondary or acute care "*is concerned with emergency treatment and critical care involving intense and elaborate measures for the diagnosis and treatment of a specified range of illness or pathology. Entry into the system at this level is either by direct admission to a health care facility or by referral. Provider groups for secondary care include both acute- and long-term care hospitals and their staffs.*" [8]

Tertiary care "*includes highly technical services for the treatment of individuals and families with complex or complicated health needs. Providers of tertiary care are health professionals who are specialists in a particular clinical area and are competent to work in such specialty agencies as psychiatric hospitals and clinics, chronic disease centers, and the highly specialized units of general hospitals; for example, a coronary care unit. Entry into the health care system at this level is gained by referral from either the primary or secondary level.*" [8]

Respite care "*is that provided by an agency or institution for long-term care patients on a short-term basis to give the primary caretaker(s) at home a period of relief.*" [8]

Restorative care "*comprises routine follow-up care and rehabilitation in such facilities as nursing homes, halfway houses, inpatient facilities for alcohol and drug abusers, and in the homes of patients served by home health care units of hospitals or community-based agencies.*" [8]

Continuing care "*is provided on an ongoing basis to support those persons who are physically or mentally handicapped, elderly and suffering from a chronic and incapacitating illness, mentally retarded, or otherwise unable to cope unassisted with daily living. Such care is available in personal care homes, domiciliary homes, inpatient health facilities, nursing homes, geriatric day care centers, and various other types of facilities.*" [8]

2.1.2 Challenges

This section is inspired of the Encyclopedia of Health care Information Systems [10, pages xxxii–xxxiii].

Today, the health care organizations have to face three major kinds of challenges: demographic challenges, technology challenges and financial challenges. Demographic challenges concern the longer life expectancy and an aging population. The technology challenges, the acquisition of equipment at the cutting edge of technology to keep people younger and healthier. And financial challenges concern the escalating costs of treating everyone with the latest technologies and providing good care at an affordable price.

In order to face challenges, health care organizations focus on three key solution strategies which are interconnected and have an impact on each other in a way that all three are necessary to meet the objectives:

1. *Access*—caring for anyone, anytime, anywhere.
2. *Quality*—offering world class care and establishing integrated information repositories.
3. *Value*—providing effective and efficient health care delivery.

Access to health care for anyone, anywhere, and at any time is still an ambition to be reached where ICT has a crucial role to play in improving access to health care. ICT provides not only cheap communication between physician and patient or between hospitals, but also provides a secure and private lifetime computer-based record of a patient's key health history and care within a health system as known as Electronic Health Record (EHR).

Quality in health care has six key goals:

1. Safety: Avoiding injuries to patients from the care that is intended to help them.
2. Effectiveness: Providing services based on scientific knowledge to all who could benefit and refraining from providing services to those who will not benefit (i.e., avoiding under-use and overuse).
3. Patient-centered: Providing care that is respectful of and responsive to individual patient preferences, needs, and values and ensuring that patient values guide all clinical decisions.
4. Timeliness: Reducing waiting and sometimes harmful delays for both those who receive care and those who give care.
5. Efficiency: Avoiding waste.
6. Equitability: Providing care that does not vary in quality based on personal characteristics.

Value of health care is defined in a primary manner as the goal of increased productivity. But it can also be defined by putting oneself in somebody's shoes. In the patient's view, the value would be to spent less time to receive care (especially in emergency departments), be reassured while obtaining care by knowing more about the procedure for instance, and increasing satisfaction with the experience. In the physicians' and clinical support personnel's view, the value would be to have better monitoring and better access to medical records. And in the managers' and investors' view, it is primarily a monetary compromise to minimize the cost while maximizing the health care quality.

This Master's Thesis, and in particular our case study, aims to address only a few of the above challenges. The main objective of our project is, through simulation and visualization, to become more *patient-centered*. Current health care processes and technology are not designed to minimize the inconvenience of the patient (reduce the unnecessary wait times for example). Having an access to real time process data (such as patient flow) is one way to achieve this goal. Therefore, we hope to have an impact not only on the patient-centered quality but also on the effectiveness and the timeliness qualities; and on the patient's view of the value of health care.

2.2 eHealth

In the previous section, we have introduced the importance of ICT in the field of medical care. We now define more precisely their use and impact.

The purpose of this section is to give a clear definition of what eHealth is beyond the simple people's understanding of this concept which can simply be defined by using modern information and communication technologies (ICT) in the health care domain.

We will give a general definition of eHealth, then offer an overview of typical eHealth tools and talk about eHealth in the research domain.

2.2.1 General definition

The World Health Organization (WHO) defines eHealth[2] as *"the transfer of health resources and health care by electronic means. It encompasses three main areas:*

- *The delivery of health information, for health professionals and health consumers, through the Internet and telecommunications.*
- *Using the power of IT and e-commerce to improve public health services, e.g. through the education and training of health workers.*
- *The use of e-commerce and e-business practices in health systems management.*

E-health provides a new method for using health resources—such as information, money, and medicines—and in time should help to improve efficient use of these resources. The Internet also provides a new medium for information dissemination, and for interaction and collaboration among institutions, health professionals, health providers and the public." [2]

In other words, eHealth aims to make a difference. It concerns both patients and care providers but also health care managers.

For patients, eHealth try to offer accurate, complete and accessible personal health information in order to permit safer and better coordinated care. Furthermore, having an access to reliable health information sources or automated care provider monitoring of personal health status contributes to give people a healthier life.

For the care providers, offering accurate, complete and accessible patients health information is necessary. Information sharing and decision support tools lead them to make better treatment decisions at the point of care and to coordinate care delivery with other providers.

And for health care managers, eHealth offers an access to more accurate, comprehensive and timely data to monitor health outcomes, to decrease administrative investments and be at the cutting edge of technology.

[2] eHealth could be heard under other names: Medical Informatics, Clinical Computing, Telemedicine, Telehealth, Behavioral Informatics, e-Health.

2.2.2 Typical eHealth Tools

We list here some typical tools that are part of the core services when somebody talks about eHealth.

- *Health-related informational web sites.* Many sites exist to provide people with information they can use to learn about, maintain, and improve their health. That kind of websites is more and more consulted by people looking for advice in order to deal with their symptoms or to get emotional support about their health concerns. Sometimes those information platforms are alternatives to a doctor's visit. The seriousness of those web sites must be evaluated by the person accessing the information. Most of the time, it is strongly advised to discuss the information with a doctor.

- *Mobile Health.* Mobile health (also written as m-health) concerns everything in health care which is supported by mobile devices. Mobiles devices denote not only mobile phones but also tablets, PDA (Personal Digital Assistant), etc. Mobile health applications can help physicians to collect information on their patient wherever they are in the hospitals or to get alerts when they are required for an emergency, for instance.

- *Medical Imaging.* This is one of the most important tools of eHealth. Everybody have already seen a radio showing a broken arm. But medical imaging is more than that, it includes everything that can be visualized, interpreted by health care practitioners to help them to treat a patient. Although it is less known, this also concerns the visualization of the patient Electronic Medical Record.

- *Electronic Medical Record (EMR).* "*EMRs are a digital version of the paper charts in the clinician's office. An EMR contains the medical and treatment history of the patients in one practice. EMRs have advantages over paper records. For example, EMRs allow clinicians to: track data over time, easily identify which patients are due for preventive screenings or checkups, check how their patients are doing on certain parameters such as blood pressure readings or vaccinations.*" [11]

- *Electronic health record (EHR).* EHRs, instead of storing information of a patient from only one organization like EMR, store information about the patient's health across more than one health care organization. An EHR is an EMR with interoperability, built to be shared and consulted by all people involved in the patients care. This includes the patient himself. [11]

Other tools The tools detailed above are just the main ones, others might be added to the list such as medical billing software, medical decision support systems, medical students learning platforms, etc. But our goal was to show some of the tools that are part of this wide area.

The next section will demonstrate the implication and the impact of the research, particularly academic research, on eHealth.

2.2.3 Research

eHealth is increasing in importance and attracting more and more interest in research. Research in eHealth is trying to increase efficiency in health care and to enhance the quality of health care. For instance, offering better communication possibilities between health care establishments or directing patient streams to the best quality providers. Research in eHealth is trying to find more evidence to demonstrate the value of eHealth by answering these three main questions:

- Is it worth investing in eHealth?
- Does it improve the patient, population life in terms of health?
- How could we encourage patients, professionals to make use of existing technologies?

There are many ways to answer these questions and many researches can provide a part of the answer to make a contribution to the eHealth field of study.

To define and perform researches, universities are the best places. Most of universities perform every year a lot of research in order to find significant outcomes in their field.

To improve eHealth, researches are about the support to get best practices, defining rigorous models or methods to determine quality and effects of eHealth applications. Furthermore, research tries to investigate research approaches for eHealth programs. Research also tries to understand what the health needs are and how emerging technologies can fulfill that. eHealth researches tend to be evidence-based in a sense that eHealth interventions effectiveness and efficiency should not be assumed but proven by rigorous scientific evaluation. Credible information sources on research tools and findings will give more impacts to the explanations, justifications of the answers of the three main questions above.

Academic research covers many areas in eHealth and helps to give precious results to improve health care. We will point out here some of them:

- Medical imaging,
- Patient scheduling in an emergency department,
- Patient balancing between hospitals,
- Social Networks to discover who are the key people of a hospital,
- New technologies adoption and their impacts,
- Information platform development and validation,
- IT architectures to share information,
- Studies about current issues, claims, concerns of health care stakeholders and how to fix them,
- and many more.

The present document aims to contribute by offering a method to help the decision making in a hospital emergency department.

We recommend the interested reader to have a look on the Encyclopedia of Health care Information Systems [10] for more information about studies performed by universities and their contributions.

2.3 Health care in Canada

The previous sections were dedicated to give the reader the key points to know about the health care system in general; how it works, who are the stakeholders and what kind of problems they have to face with.

In this section, we will focus on the main subject of this Master's Thesis. We will explain a particular health care system, the Canadian Health Care System.

2.3.1 Overview

The Canadian health care is very uncommon due to its two characteristics, each province controls its own health care system and its a combination of public and private sectors.

Health care as a "patchwork"

The Canada has this particularity that the health care authority doesn't belong to the Government of Canada but to the provinces. Only provincial governments can manage their health care finances and the way health services are delivered to Canadians. The direct implication of such division is that there is no national and global system across the country. There exists many different health care systems. It is why the Canadian health care system is not referenced as a "singe system" but more as a "patchwork" of provincial health care systems.

However, the Government of Canada try to influence provinces by financing them if they implement specific policies and programs, defined by the government. The goal is to low the differences between provinces. A realization of this idea is the "*Canada Health Act*" which list a set of different criteria. If the provinces meet these criteria, they are allowed to receive annual funds. [12]

Public-Private sectors mix

The other specificity of the Canadian health care system is the combination of both private and public participation. The public participation, on the first hand, refers to the implication of the government such as described above. In addition to that, the public sector may provide and fund health care services by employing professionals, managing clinics or by being involved in some health insurances. Public entities example can be seen on Figure 2.1

The private sector, on the other hand, is involved by providing care services through private for-profit or non-profit clinics or by providing private health care insurances. The private sector is made of different entities such as those presented on Figure 2.2. [12]

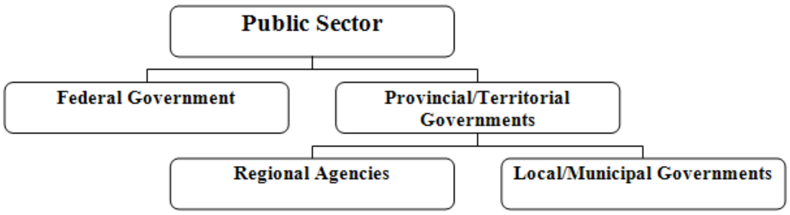

Figure 2.1: Public sector entities

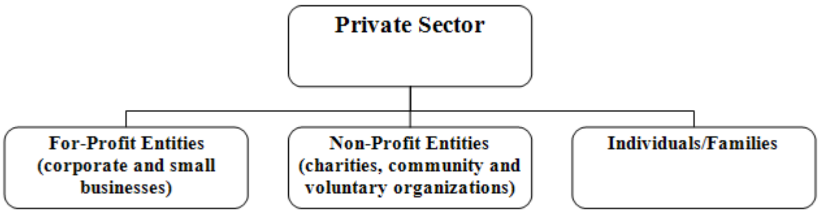

Figure 2.2: Private sector entities

Centralization desire

Due to this decentralized architecture of the health care system delivery, some actions have been taken in order to flatten the differences between them.

The first example is the actions taken by the government of Canada explained above. A second example is the "*The Canadian Health Record Interoperability Infrastructure*" [10, pages 188-193]. The maim idea is to integrate as many as possible systems to facilitate the exchange of information between these systems and improve their efficiency. The *Health Canada Infoway* groupe has been created in this direction to develop a "standard" electronic health record. This permits hospitals to more easily exchange patient data.

2.3.2 Canadian Triage and Acuity Scale (CTAS)

The *Canadian Triage and Acuity Scale* (CTAS) has been developed by the Canadian Association of Emergency Physicians (CAEP) to be a tool used by nurses in emergency departments for the patients *triage* process to assign a level of severity of illness. Goals of the triage are [13]:

1. *"To rapidly identify patients with urgent, life threatening conditions.*
2. *To determine the most appropriate treatment area for patients presenting to the ED.*
3. *To decrease congestion in emergency treatment areas.*
4. *To provide ongoing assessment of patients.*
5. *To provide information to patients and families regarding services expected care and waiting times.*

6. *To contribute information that helps to define departmental acuity."*

The scale consists of five levels and is related to the time to see a physician. Level I involves a critical state and immediate treatment, and level V concerns non-urgent care conditions. The time responses are defined to be *ideals objectives to be achieved* and not rules that every hospital has to respect. They are based on a patient focus and the need for timely intervention to improve outcome. The CAEP also defines that patient should have an initial triage assessment within 10 minutes of arrival.

Level I: Resuscitation "*Conditions that are threats to life or limb (or imminent risk of deterioration) requiring immediate aggressive interventions.*" [13, page 11]

It includes patients with cardiac and/or pulmonary arrest (or appears to be imminent), patients with a major trauma, patients in shock state, unconscious patients and patients with severe respiratory distress.

The recommended time to be assessed either by a nurse or a physician is **immediate**.

Level II: Emergent "*Conditions that are a potential threat to life limb or function, requiring rapid medical intervention or delegated acts.*" [13, page 12]

It includes patients with head injuries, patients with severe trauma, patients with serious pain, patients with overdose, patients with severe asthma, etc.

The recommended time to be assessed by a nurse is *immediate* and by a physician is **within 15 minutes**.

Level III: Urgent "*Conditions that could potentially progress to a serious problem requiring emergency intervention. May be associated with significant discomfort or affecting ability to function at work or activities of daily living.*" [13, page 17]

It includes patients with moderate trauma (fractures, dislocations or sprains with severe pain), patients with vaginal bleeding and pregnancy, patients with acute psychosis and/or suicidal, patients under two years old with vomiting and or diarrhea, dialysis patients, etc.

The recommended time to be assessed either by a nurse or a physician is **within 30 minutes**.

Level IV: Less Urgent (Semi urgent) "*Conditions that related to patient age, distress, or potential for deterioration or complications would benefit from intervention or reassurance within 1-2 hours).*" [13, page 19]

It includes patients with minor trauma (minor fractures, sprains, contusions, abrasions, lacerations requiring investigation or intervention), patients with headache or ear ache, suicidal/depressed patients, patients with back pain, patients above two years old with vomiting and or diarrhea, patients with upper airway congestion, cough, aches, fever, sore throat, etc.

The recommended time to be assessed either by a nurse or a physician is **within 60 minutes**.

Level V: Non Urgent "*Conditions that may be acute but non-urgent as well as conditions which may be part of a chronic problem with or without evidence of deterioration. The investigation or interventions for some of these illnesses or injuries could be delayed or even referred to other areas of the hospital or health care system.*" [13, page 21]

It includes patients with minor trauma (not requiring closure by any means), patients with normal menses, psychiatric patients, etc.

The recommended time to be assessed either by a nurse or a physician is **within 120 minutes**.

Later in this document we may refer the CTAS using two groups. The first one includes the most sick patients namely the CTAS levels I & II. The second group includes the remaining levels: III, IV and V.

2.4 Conclusion

In this chapter, we have defined what is the health care system, pointing the various medical facilities and the six levels of health care. We also explained the current challenges of health care and that our objective is to help the health care to be more *patient-centered*.

We have given a more clear definition of eHealth, presented the typical tools employed in eHealth and have put emphasis on the importance of universities' involvement in the research domain.

Finally, we presented the characteristics of the Canadian health care system, and more particularly the Rouge Valley Health System, our valued partner for this project.

Road map

The Health Care domain is really wide and could be the subject of a whole book. Therefore, in this chapter, we have only been focused on providing the reader with a good overview of what it is in order to stay focused on the emergency departments.

In the next chapter, we will describe one particular actor of the health care system, namely the hospital. We will also explain how an emergency department works and will introduce the typical issues that EDs have to deal with, why they have those problems and how we can try to address them.

Chapter 3

Hospitals

3.1 General purpose

Before going in full detail about the emergency department, this chapter will give an overview of hospitals. Even if it is a well known word, we will deeply describe in which context our work will take part. The hospital is a big environment with a lot of different departments, core business, type of employees but also a lot of pressure to ensure a minimum quality of service. This microcosm has also this ambivalence feeling with, on the first hand the duty to save lives and provide the best service for every patient and, on the other hand, the need to have a growing benefit, like every companies.

For the outside, a hospital is just a big entity but from the inside it is more than that. Indeed it consists of interactions, sometimes not easy, between a set of departments. These departments will be described in the next section. We will next focus on the people and equipment tied with these departments and we will present some problems and limits concerning all the management of the staff. After that, the emergency department will be described in more detail. This department is, in the most cases, the critical point of a hospital because it is from where the biggest flow of patients is coming in and therefore it is where the performance is the priority.

3.2 Departments

A hospital is always made up of a set of different departments. Hospitals differ in their organizational structure but we can categorize the hospital departments in three parts. The first one contains the departments which manage the whole hospital. The second one is focused on the employees and the cleaning service. The last kind of department is the most important in our purpose because it is focused on the patients and constitutes the core business of a hospital.

3.2.1 Management departments

Hospital management departments resemble those in other, non-health care organizations. They are made, for instance, of the *Human Resources Manage-*

ment, the *Administration Management* and so on. Because these departments are sometimes the same from one hospital to another, it happens that the management departments are detached and externalized in a separate company, which then manages a bunch of hospitals.

3.2.2 Staff departments

This kind of department does not have a lot of importance in our case because it only concerns the cleaning services and building maintenance for example.

3.2.3 Patient departments

These departments are the most important in the hospital because they are in direct relation with the patients going through the services. Each department has its own specialties with the appropriate equipment and staffs. Even if each hospital has a specific and unique departments configuration, some of them will always be present.

Coronary care unit The coronary care unit is specialized in everything concerning the heart (heart attacks, cardiac dysrhythmia, etc.). Depending on the hospital, this unit can be divided into several parts by level of severity.

Critical care unit As the name of this ward says, it concerns all the patients who need a constant and close monitoring. Most of the patients have life-threatening conditions and therefore need the best equipment and complete team of specialists.

Emergency department This department is an *entrance* of the hospital. Its goal is to threat acute patients with different levels of seriousness. Because this department is in the center of this document, it will be detailed later in the section 3.4.

Geriatric care unit The speciality of this unit is the treatment of elderly persons. This ward tends to be increasingly important due to the aging population.

Pediatric care unit The pediatric care unit is specialized in the care of infants, children and teenagers. We can possibly find a higher rate professionals/patients in this unit.

3.3 Staff & equipment

A wide range of different kinds of employees is present in a hospital and, in order to help them, a lot of specific equipment with, in some cases, unique tools dedicated to a precise job. In consequence of the division between the types of departments, the employees can be categorized into two kinds, the *clinical workers* and the *non-clinical workers*. In other words some workers are in direct relation with the patients and other workers are not.

Another distinction between the employees we can find is the difference between the external and internal professionals. For instance, in some countries such as the Canada, the surgeons are relatively independent from the hospital.

3.3.1 Clinical workers

The clinical workers and professionals are the more closely linked with the patients. The most usual kinds of workers are [14]:

- Physician (ER doctors, surgeons, hospitalists)
- Nurse (Certified Registered Nurse Anesthetis, Registered Nurse, Licensed Practical Nurse/Licensed Vocational Nurses, Clinical Nurse Specialist)
- Techs (Radiology Tech, Ultrasound Tech, Surgical Tech)
- Therapist (Physical Therapist, Radiation Therapist)
- Medical Assistants
- Pharmacists
- Medical Lab Technologist
- Dietitian

These workers are then dispatched between all the departments and will constitute teams in order to be more efficient in the health care delivery.

3.3.2 Non-clinical workers

This kind of workers constitutes the biggest part of workers in the staff and management departments. As examples we can have [14]:

- Case manager / Social Worker
- Accountants
- Human Resources & Recruiting
- Executives — Chief Executive Officer, Chief Financial Officer, Chief Information Officer, Chief Marketing Officer
- Information Technology
- Administrative Assistants

3.3.3 Equipment and technologies

With the duty to provide the best service for patients, hospitals have to use a wide range of specific equipments. For example, we can find in the hospital centrifuges, dryers, electrocardiograms, incubators, etc. A complete list of lots of different tools used in an hospital can be found in the document of Ramesh Guragain et al. [15].

3.4 Emergency Department

The emergency department is in the most important wing in a hospital because of the number of patients going through it. This project will be focused only on this department. Analyzing and working on all the departments present in one hospital would be beyond the scope of this thesis because of the number of parameters and the time required. Thereafter is the wide view of the goals, objectives and challenges of this department together with a description of some typical activities.

3.4.1 Purpose of the emergency department

An emergency department can be defined as follow:
"*Emergency Departments (EDs) were primarily established to treat seriously ill and injured patients, 24 hours a day, seven days a week, who need immediate care. In practice, however, EDs strive to provide timely care to all patients regardless of why they are seeking care. [...] Unlike how other health services are organized, EDs have unique characteristics. For example, the majority of visits to EDs are unexpected and unscheduled and involve immediate assessment. At times, decisions about treatment need to be made very rapidly and actions need to be taken immediately.*" [1]

Consequently, this department faces challenges due to the variety of illness and the almost unpredictable flow of patients arriving in the hospital. An emergency department is a smaller version of a complete hospital considering it has its own environment to provide care to patient and has its own administrative processes. Indeed, a patient can enter into an emergency department, be diagnosed and assessed and finally be discharged when her medical problem(s) addressed. And everything is done within the emergency department only.

A typical emergency department will contain these major functional areas [16]: ambulance and ambulatory entrances, reception/triage/waiting area, administrative area, resuscitation area, acute treatment area, consultation area, fast track area, staff workstations, specialty areas (eg., pediatric areas, procedure room(s), staff rooms, mobile equipment bay). Diagnostic areas (eg., medical imaging unit or laboratory area) and emergency department short stay/observation ward are optional areas but are often found in an emergency department.

We now describe what is the typical path for a patient who requires the services of an emergency department.

3.4.2 Typical process for a single patient

This section is inspired by the draft written by Mark Smith and Craig Feied: *The Emergency Department as a Complex System* [17].

We can say that there are three ways to go to the emergency department. The first and most important one is when the patients come by their own means. We will next reference these patients as the *walking patients* or *walk-in arrivals*. The second way is the ambulances, with the dedicated employees and the special process which occurs when the patient is transferred between the ambulance staff and the emergency department staff. The last one is the helicopter but it is not present in all hospitals.

In contrast to these three ways to enter in an ED, there are also three ways to leave an emergency department. A patient can be admitted to the hospital and receive extra care in another unit of the hospital (see subsection 3.2.3) or be transferred into another health care facility to receive specialized care or balance the patient flow, for instance. A second way to leave an emergency department is to be discharged by a doctor considering her patient's health good enough to go back home. Some patients do not complete the full flow of activities of the ED and leave without being seen or choose to leave against medical advice[1]. Finally, the third way to "leave" an emergency department is when a patient dies in the ED, often referred as "*expired*" patient.

Between these two extreme cases, the patient will walk through a series of diagnostic testing encounters and one or more therapeutic interventions.

Typically, the patient is initially assessed by a nurse through the "*triage*" stage. "Triage" is the term derived from the French verb "*trier*" which means "*to sort*" or "*to choose*". This process classify patients by the type and urgency of their conditions and intends to get the right patient to the right place at the right time with the right care provider. Most of the time, the patient's health is mapped on a scale of illness severity such as the Injury Severity Score (ISS) or the Canadian Triage And Acuity Scale (detailed in section 2.3) and a color code is also often attributed (red for the most serious cases, for instance).

Then the patient is evaluated by a physician, who can ask for a series of diagnostic tests such as x-rays, electrocardiogram, and blood tests. Depending on the emergency physician's assessment and test results, a series of therapeutic interventions can be initiated. While all this is happening, the patient is continuously being monitored and reevaluated by machines, nurses, and physicians. Depending on information obtained by this continuous monitoring, more tests can be processed and/or interventions can be performed. Also, some patients who are not mentally stable, may need special attention.

At some point, a decision is made whether the patient needs to be admitted to the hospital or can be safely discharged home. An administrative disposition process then occurs in which the patient's ED encounter is administratively "closed out". No two paths through this system are the same for two different patients. Decisions by emergency physicians and emergency nurses, as to what specifically to do next for the patient, are continuously being made and modified. It is based on information about the patient that reveals itself and unfolds in real time.

In the Rouge Valley Health System (RVHS)

Despite the fact that all EDs are different, they all "implement" the same "flow of activities"[2]. We now briefly describe the specificities of our hospital partner (see Figure 3.1[3]).

---

[1] Designated as "Left Without Being Seen" (LWBS) patients.

[2] We recommend to read "*Emergency department generalized exible simulation model*" [18] which depicts a general simulation model for an ED and explain in more detail the internal operation of such department.

[3] This figure was provided to us by Mr. Topaloglou and is used for health care presentations.

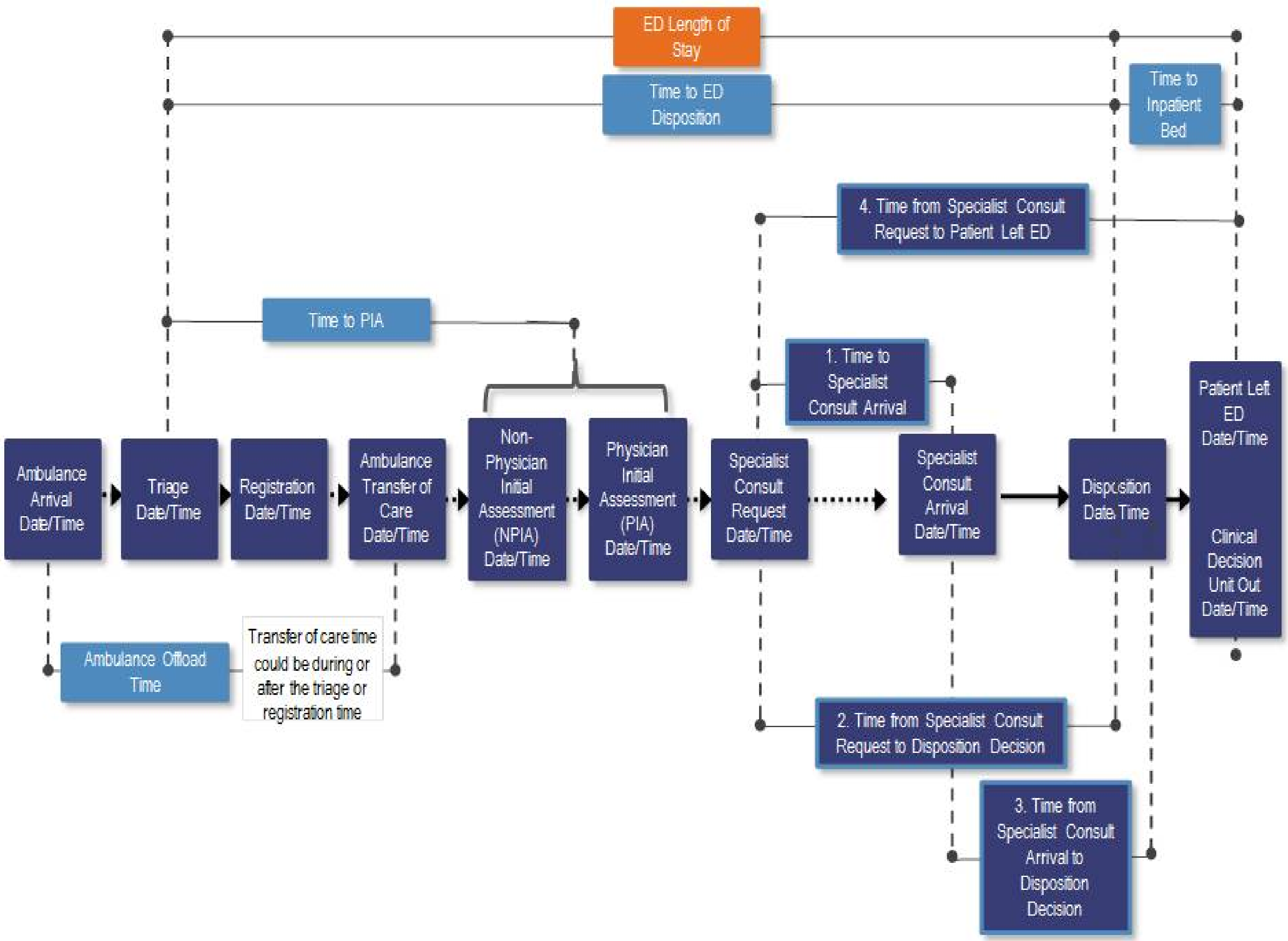

Figure 3.1: Flow model of the emergency department

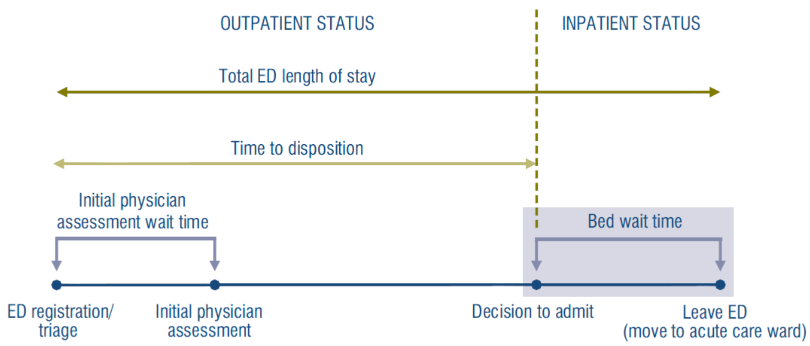

Figure 3.2: Emergency department wait time

We can see on Figure 3.1 that the beginning of the process is basically the same as previously described. The RVHS hospital does not receive patient by helicopter.

The light blue boxes represent which metrics the emergency department are recorded. The ambulance offload time is the time between the ambulance arrival and the Ambulance Transfer Of Care (ATOC), when the patient comes under the responsibility of the hospital.

It is important to specify that the two steps of triage and registration can be skipped in the case of CTAS I & II levels, the paperwork is thus done afterwards.

The patient is assessed by a physician who will decide to discharge the patient or ask for more examinations. If so, a specialist is required to admit or not the patient in the hospital. Our ED partner records four metrics for the specialist represented by the four numbered dark blue boxes.

At the end of the process, we can see that this emergency department implement a Clinical Decision Unit (CDU) which is a special unit within the ED whose purpose is for observations for certain patient populations, such as cardiac failure.

3.5 Wait time and overcrowding

As it was shown above, the emergency department is a complex environment with, sometimes, the help of the information technologies. Nevertheless this department is subject to several typical issues, some of them related to the eHealth tools and others related to the specific nature of this ward.

Probably the most important problem about the emergency department is the high wait time for some patients. Many researches and articles have been done about this issue and it is still the most discussed concern. It is important here to make the distinction between the wait time from the moment when the patient enters the emergency department and when this patient is seen by a physician, and the wait time between the ED and another ward. For instance, sometimes patients have to wait after a consultation to get an inpatient bed. In that case, this phenomenon is called *Bed Wait Time* [6]. section 3.5 presents the difference between both kinds of wait time.

3.5.1 Causes

For the first kind of wait time problem, the most obvious cause is the aging demographic. The direct consequence of it is the need for more places, more nurses, more physicians and more beds. Unfortunately it is not proportional and, in some cases, the staff has to treat more patients with the same resources than before.

Another cause is that some patients prefer to be assessed by an emergency department physician than a regular doctor. A survey done by the Commonwealth Fund in 2004 shows that 18% of the adults going into the ED felt that they could have been treated by a regular doctor if available and more than 50% of patients in a ED are not in urgent condition (CTAS level IV and V) and do not need specific care [1].

A third cause is a direct consequence of the *bed wait time*. Because some patients have to wait to be transferred to another department, they are using bed and resources. With the snow ball effect, the wait time concerning patients to be seen by a physician is impacted by the wait time of patients waiting to be admitted in another ward.

Next cause is the fact that, due to the high diversity of care in the department, some medical specialists have to provide services. Unlike emergency physicians which are up 24 hours a day, specialists are not always available when needed and then patients have to wait.

A last explanation of the overcrowding and big wait time is the local crises and disasters, which are totally unpredictable and need an immediate medical care.

3.5.2 Impacts

Based on "*Systematic review of emergency department crowding: Causes, effects, and solutions*" [19], we can spot four main impacts of the overcrowding in the emergency department:

- *Increased average time before a patient is seen by a physician.* This can possibly raise her illness but certainly reduce his satisfaction about her stay in the hospital. Some tragic cases can be found in the news about patients dying in the emergency department waiting room (an example can be found in [20]). The increased mortality is then a matter of great concern [21].

- *Overextended hospital crew.* The risk of errors raises and can lead to dramatic consequences in the worst scenario.

- *Impaired access to care.* Due to a full emergency department, ambulances have to choose another hospital where to bring a patient. This phenomenon is called the *ambulance diversion* and delays the delivery of care.

- *Provider losses.* This last effect of the overcrowding is benefits lost by the hospital because of the increased costs.

3.5.3 Solutions and improvements

Because of the high critical state of the overcrowding and wait times in the emergency department, many researches have been done in order to find a way to improve the number of treated patients. The range of solutions will be divided in three parts as follows:

Population sensitization Population education through campaigns is important because it can clarify what types of illness are appropriate for the ED or can be handled by a traditional doctor. People can also verify, if the hospital equipped whether the wait times in the emergency department are high or not. The last point is the phone calls. Possible patients can make a phone call to the hospital to get a quick report and if a visit to the ED is needed or not.

Government actions Government can also play a role in this decreasing of wait times and overcrowding by allowing budgets to hospitals or promote the nurse and physician profession. In addition to these actions, in some countries the decision was made to define a threshold for the emergency department length of stay (EDLOS). For example, Australasia and United Kingdom introduced the *four hour rule* which states that at least 98% of the patients must be treated within four hours [22, 23].

Technological solutions Some technological solutions have been developed such as the dash-boarding for nurses and physicians, online state of the wait time, RFID[4] tracking system and so on. A whole bunch of professional *Emergency Department Information Systems (EDIS)* are available (an informal list can be found at [24] and [25]) trying to help the staff in the day-to-day work but also when problems or patients peaks appear. This part will be more detailed in section 4.1.

3.6 Conclusion

The hospital is a very complex microcosm with a lot of challenges from a wide range of parts. More complex, an emergency department is considered as an entire system itself and deserves special attention.

It is in this problem domain that this thesis will take part because this problem is not isolated and is related to a multidimensional context with lots of different factors.

Road map

Now that we see how challenging it is, we will show how the technologies and IT try to improve (sometimes without any success) the quality of care or can help the staff, the management crew and the patients. We will see that the simulation and visualization can be seen as a means to prevent the overcrowding and big wait times in emergency departments.

[4] Radio-Frequency IDentification.

Chapter 4

Methodology

4.1 Overview of solutions

Now that the context of this work is clear and that the environment is understood, it is important to make a very wide view of what has already been developed in emergency departments and what solutions do exist and for what purpose.

In response to the high level of diversity of patients and the critical need for responsiveness, many solutions exist both from researchers and private companies. Some of them are more focused on the management view like the *Emergency Department Information System (EDIS)* and the others have been developed to tackle the overcrowding problem. These two kinds of solutions will be described below with some examples.

4.1.1 Electronic Medical Record and Electronic Health Record

As seen earlier, the *Electronic Medical Record (EMR)* is a digital version of the medical record composed of paper reports and notes from a health care provider. To cope with the need of interoperability between the health care providers, the *Electronic Health Record (EHR)* was introduced. But we can easily understand that it is very challenging to create a standard object across many different health care providers. Basically, each hospital uses its own EMR management system without even thinking about interaction with another hospital. A survey done in 2006 reveals that there are more than 40,000 different medical information systems [26]. It is in this vein that some researchers try to create a main platform across Canada. An example of this idea is the *Canadian Health Record Interoperability Infrastructure* [10]. In contrast with projects in other countries, this one aims to avoid the use of a centralized database nor a totally distributed collection of systems. The platform created is a compromise between both.

4.1.2 Emergency Department Information System

As the emergency department is a very important ward in the hospital that needs to cope with a high throughput of patients, emergency department information systems were developed with the intention of providing monitoring and managing tools. Every EDIS tends to provide two kinds of functions. The first one concerns the patient and includes functions such as patients triage, results reporting, order entry, patients tracking, department dashboards and so on. This kind of functions is mainly manipulated by the nurses and physicians on a daily basis. The other kind of functions provides information for the administrative staff and includes hospital statistical metrics, billing, disease surveillance, integration with other hospitals or with public information, etc. [27]

Emergency department information systems are now very widespread. A big goal for some organizations and countries is to increase interactions between these systems. For example, the *Canadian Emergency Department Information System (CEDIS)* was launched by some associations in order to create common information gathering systems for the emergency department [28].

4.1.3 Wait times solutions

As it was already described in section 3.5, the overcrowding and high wait times constitute the main challenging problem to be addressed. Several solutions exist in order to solve this important problem. Nathan R. Hoot and Dominik Aronsky [19] assert: "*Three general themes existed among the solutions of ED crowding: increased resources, demand management, and operations research. Increased resources reflected the deployment of additional physical, personnel, and supporting resources. Demand management reflected methods to redistribute patients or encourage appropriate utilization. Operations research reflected crowding measures and offline change management techniques.*" For the purpose of this work, only the last theme of solutions will be described. The first two are more management-oriented.

Queuing theory Many research have been done about the queuing theory and its application in the emergency department. The simulation of the emergency department is directly linked with queuing theories and is used to try to predict how the flow of patients will go. As the simulation tools are more and more complete and full of options, models tend to be more precise and close to the reality, allowing the management crew to better allow resources when and where it is needed. The queing theory will be explained in more detail in chapter 5.

Business intelligence Another solutions theme is the *business intelligence (BI)*. The BI can be defined as "*[...] the ability for an organization to take all its capabilities and convert them into knowledge, ultimately, getting the right information to the right people, at the right time, via the right channel.*" [29] By using such field, top managers are able to get relevant information with multidimensional aspects (for example, the average number of patients staying in the waiting room, for a specific day, when the number of nurses is very low).

EDIS An Emergency Department Information System could help lowering the overcrowding in the department by providing tools to assist nurses and physicians. The limit between an EDIS and the business intelligence is sometimes very tenuous in the sense that some EDIS use BI techniques. Also, these systems are mostly coupled with visualization tools.

Visualization tools Visualization tools allow the staff and administration to have a global view of the department and point out where problems occur. Their main goal is to decrease the length of stay of patients and reduce costs for the hospital. This can be done by a better view of the flow of patients going through the department. Visualization tools are, most of the time, encompassed in an EDIS. There exist different kinds of visualization tools. As we chose to develop this aspect in this document, this will be explained in more detail in subsection 4.2.2 and section 6.2.

4.2 Chosen approach

Our choice fell on the simulation and the visualization in order to improve the emergency department quality of care. Figure 4.1 is an overview of our methodology.

It first starts with the obtainment of the RVHS data followed by a data processing. It will give us the set of data which will be used for this project. In addition to this set of data, we learned the context and defined the problems and objectives.

From that point, the project is divided in two parts with, on the first hand, the simulation model and, on the second hand, the visualization tool. Both yellow rectangles are detailed in Figure 4.9 for the simulation and Figure 4.10 for the visualization.

As output of the simulation and visualization, we will get some results on which we will perform some analysis in order to get useful information. At the end of the procedure, the review will criticize the results and judge our methodology.

4.2.1 Simulation

Motivation

We first chose to realize a simulation model. Simulations are increasingly used in health care in order to study the behavior of a system and the interactions between its components on the basis of concrete data, of concrete systems.

The target model, described in detail in section 4.3, has as primary objective to be a high-fidelity representation of the patient flow and of the patient care process within an emergency department.

The simulation model will simulate everything that happens in an emergency department, from the arrival of a patient until her discharge or her admission into the hospital. We do not only consider the patient flow, but also the presence of doctors and nurses, which provide diagnoses to patients and appropriate care for a prompt recovery. Furthermore, many diagnoses are made by considering the results of tests performed on patients (blood test, urine test, etc.). It is a whole world that must be captured in the simulation model to guarantee that it will fairly represent the reality and then, to perform what-if analysis using this model.

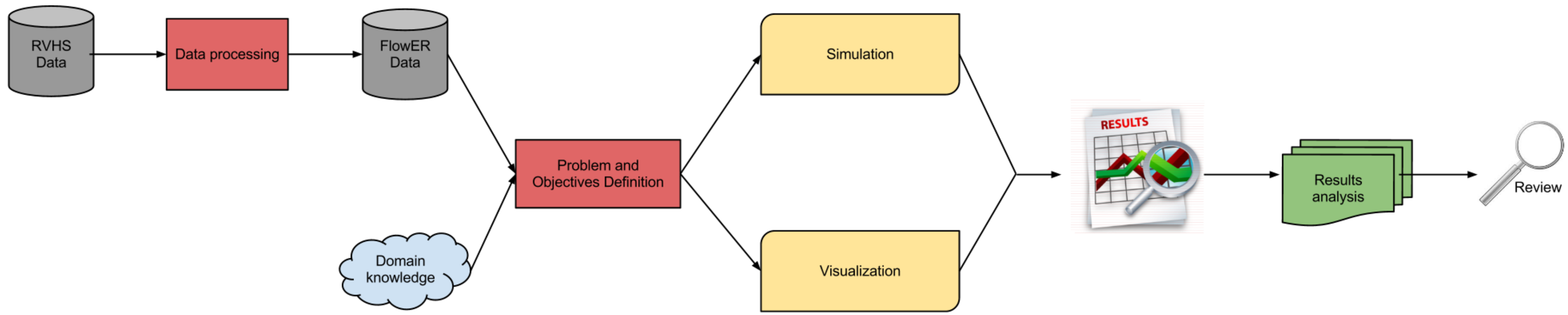

Figure 4.1: Methodology overview of the FlowER project

Simulation in health care

Simulations in health care domain are appropriate because they allow to encapsulate at the same time the management issues of the patients, the medical staff and the medical equipment (X-Ray, etc.). Simulations also allow to handle problems of internal decisions, providing a tool for decision support to answer questions like *should we improve the process of blood testing considering that it takes more than X minutes?* Finally, simulations can manage the cost of the resources which are used in the simulated department.

Through the simulation model, the internal logic of the system to be simulated will be translated according to reality and available data of the system. Such data are provided by the persons in charge of the system, and in the form of data in a database and/or Microsoft Excel files, technical reports, interviews with key players of the system, etc. Any information may prove to be useful for the construction of the simulation model.

However, a simulation model is not only developed in order to reflect the reality, since it would be easier to directly study the system already in place[1]. The strength of a simulation model lies in its capacity to manage variability. Although both will follow the same trend, two simulation runs of a same model should allow to study different results. In our case, it may simply result in different inter-arrival times or the decision of performing an additional test on a patient. Furthermore, a simulation model is used to test assumptions. Thus, the different model parameters are modified at will in order to study the system in other conditions than the initial ones and answer questions such as: *is hiring an additional nurse for night shift a good option?* Or, *what would be the number of beds to be added to increase the performance and to be more efficient?*

Finally, simulations are also valuable for their aspect of "*low cost*" and "*low risk*". In fact, developing a simulation model costs significantly less than testing new policies directly on the existing system. For the same reasons, there are very few risks to conduct a study through a simulation model. The risks lie in the results and the message that is transmitted to the management team. This is also why the simulations are attractive to the medical field. They have the advantage to allow the modeler to define relevant metrics to analyze. These may be general or specific to the field of the system. Such freedom of information reading also allows a deeper understanding of the system thanks to the new data generated that were not considered useful or were not possible to be measured before.

Other case studies

To support our argument of increasing popularity of the use of simulations in the health care domain, we will present four case studies. There are many others but we selected them to show that: (1) simulations in the health care domain are performed for many years; (2) various types of simulation exist; (3) the considered problem can be highly specific; and (4) the problem we are trying to

[1] This is not always true. Indeed, some simulation models are developed to study the behavior of a system *before* its implementation.

address has already been the subject of a study but in a different context and under other conditions.

The use of simulations in the health care domain is not new. Indeed, in 1987 Thomas D. Clark, Jr. and Craig W. Waring wrote the article "*A simulation approach to analysis of emergency services and trauma center management*" [30] and they, in turn, cite in their introduction many other studies based on the use of simulation in the medical field.

The goal of their study was to "*improve the scheduling of professional staff delivering emergency care*". In other words, this is a study which attempts to determine what would be the optimal allocation of human resources in a trauma center. The easiest solution would be to hire a very large number of physicians and nurses in order to provide care to all patients. This is obviously not the most optimal solution both in terms of cost and in terms of resource utilization. So they built a simulation model taking these parameters (among others): the number of physicians and their schedules, the number of nurses and other medical staff, the structure of the facility, the processing time of the patient, preparation time and time responses of ambulances. They present in their paper their model and its different operations, and expose the different tests in the allocation of staff.

There are several types of simulations as we will explain in the chapter dedicated to the simulation theory (chapter 5). The second case study we present here uses one of them, namely "the agent-based simulation".

"*An Agent-based Simulation for Workflow in Emergency Department*" [31] is a paper having two objectives "*(1) to develop an agent-based simulation to allow free exploration of the ED performance under various settings; (2) to characterize and study the ED performance under different settings of the triage process and radiology procedure process*".

An agent is an autonomous entity able to do different actions and interact with its environment. Basically, an agent-oriented system is made up of several agents interacting among themselves. The Figure 4.2 represents a screenshot of the simulation.

The input of this study is essentially the same as the previous case, namely characteristics about: patients arrival, triage, physician and nurse care, and about radiology order. And the output is a model allowing to study the workflow and test the impact of potential modification. Furthermore, agent-oriented modeling allows to better understand the interactions between the various agents.

The next article that we introduce, "*A simulation model for bed allocation to hospital inpatient departments*" [32], wants to be focused on a very specific matter. The author wishes to address the problem of efficient allocation of beds in the emergency department and tries to determine the bed complement in hospital inpatient departments to meet a predetermined demand for service. To do so, the model will be filled with practically the same information as for the previous case studies but additional constraints are imposed: "*(1) emergency patients should be admitted without delay, (2) occupancy should not fall below a pre-specified level, and (3) the waiting list length should not exceed a predetermined number*".

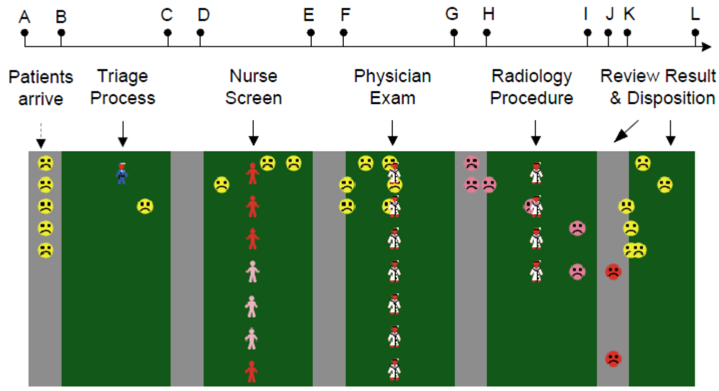

Figure 4.2: Simulated ED workflow and simulation screenshot of the second case study.

Therefore, a simulation model can be used to study highly specific cases and to provide a solution to a subset of a more general problem.

The last article we present in this section has a very similar goal to the one we have set ourselves and that we describe in subsection 4.3.2.

"*Modeling and analysis of the emergency department at university of Kentucky Chandler hospital using simulations*" [33] is a study performed for "*analyzing the patient flow in emergency department to minimize length of stay, improve efficiency, and reduce overcrowding*". Figure 4.3 represents how they modeled the patient flow which is described in subsection 3.4.2. In the end, their model, through what-if analysis, helped them to discover that extra nurses are needed to ensure better health care. They also discovered that the computed tomography scan was the subject of a bottleneck and made the recommendation to buy an additional scanner.

Other case studies with the same goal have been performed on particular emergency departments and each of them has been able to offer a simulation model that correctly simulates the patient flow and allows the authors to study other scenarios. Our simulation model has the same goal and we will explain precisely in the following chapters what are our objectives and what our simulation model provides to the emergency department we were working with.

4.2.2 Visualization

Motivation

In addition to the simulation model, we chose to create a new visualization interface for the emergency department. Visualization tools emerged at the same time as when the hospitals started to collect all kinds of information about patients. They have an increasing amount of data in their databases and needed a good way to infer useful information and some support in the decision making process. Another subject of matters is to know how to capture the flow of patients. This patient flow has to be optimized, controlled and analyzed as

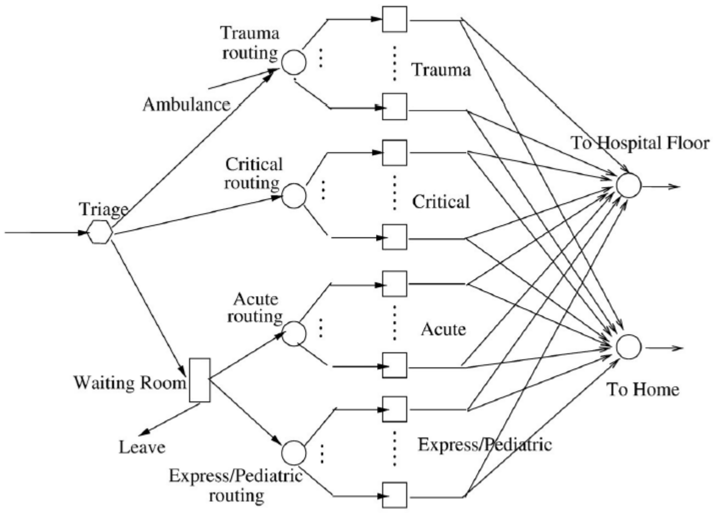

Figure 4.3: Patient flow in the University of Kentucky Chandler Hospital emergency department (fourth case study).

patients move from a medical department to another. Being able to capture this flow and visualize it can then decrease the length of stay, reduce the hospital costs but also spot some strange habits and work on it.

Dashboard

Dashboards are probably the most used kind of visualization in the emergency department and the hospital. Dashboards are the gathering of a big set of information coming from data stored in a database. They are made of charts, graphics, tables and other statistical items and are used in many other disciplines. In 2006, Stephen Few wrote the book "*Information Dashboard Design: The Effective Visual Communication of Data*" which became the reference book about how to create the perfect dashboard showing all the critical information [34].

As an example of dashboard, Figure 4.4 shows what is used by the staff in the hospital to manage departments. Some live examples can be found on the Internet and can be manipulated via the browser[2].

Tracking system

With the emergence of the *RFID* [35] technologies, new visualization tools were created in order to keep track of staff, equipment and patients. This kind of system is fairly new and tends to be slowly deployed in hospitals. The main advantage of a RFID tracking system is that "*the technology maximizes the use of equipment, reduces the amount of lost or stolen equipment, increases employee productivity, ensures patient safety, and improves patient care. The*

[2]For instance: `http://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/about+us/our+performance/our+hospital+dashboards/about+the+ed+dashboard/ed+dashboard`

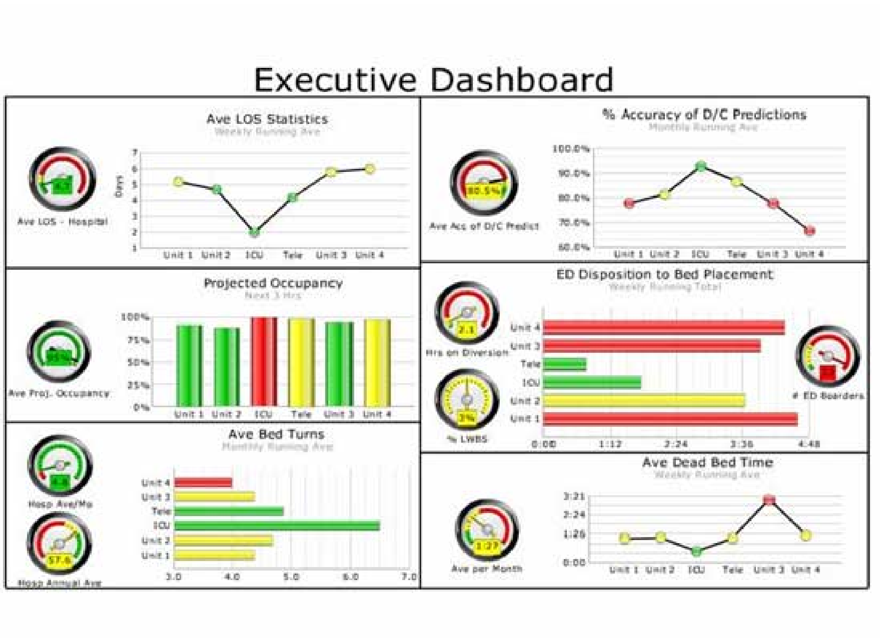

Figure 4.4: Example of dashboard used in hospital

cost savings associated with these benefits can be tremendous" [36]. Figure 4.5 shows a tracking system for wheelchairs.

Graphical representation

Unlike the dashboards, the last kind of visualization tool concerns the way we can represent the flow of patients going through the emergency department. Some researchers have used different techniques such as *Petri Nets* [37] or *state diagrams* [38]. Figure 4.6 shows how the emergency department can be represented as a state diagram, allowing interaction like focusing or zooming.

Other case studies

The way we can visualize the data coming from the emergency department for the administration and the care staff is a well-discussed subject. As it is a big part of this work, some case studies will be presented and summarized. The following case studies have been chosen because of the close relation with what we have developed.

The first article was written by Delphine Rossille, Marc Cuggia, Aude Arnault, Jacques Bouget and Pierre Le Beux under the title "*Managing an emergency department by analyzing HIS medical data: a focus on elderly patient clinical pathways*" [39]. This study is focused on a specific group of patients, the elderly patients, coming in the emergency department and the idea is to create a new set of decision support tools. This set aims to characterize this particular population in order to better anticipate their behavior and then im-

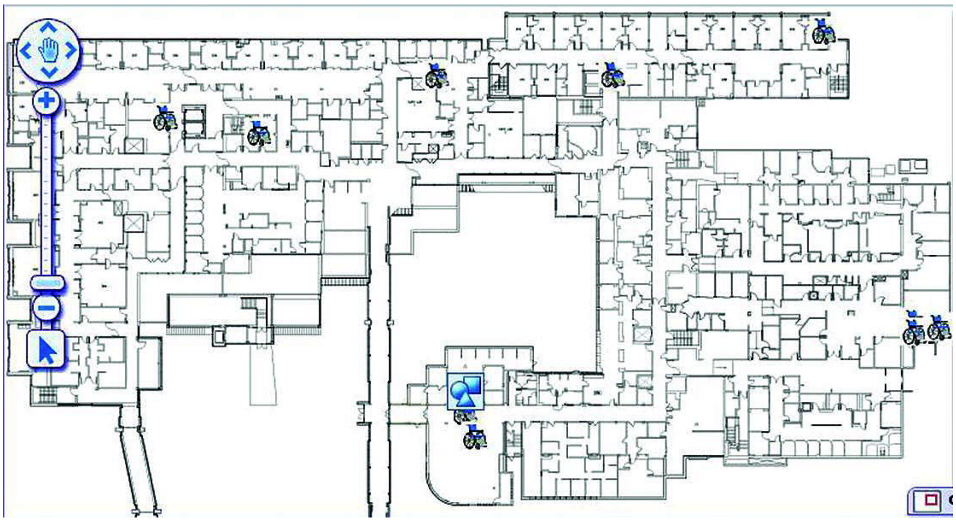

Figure 4.5: Example of a tracking system for wheelchairs

Figure 4.6: Representation of the emergency department as a state diagram

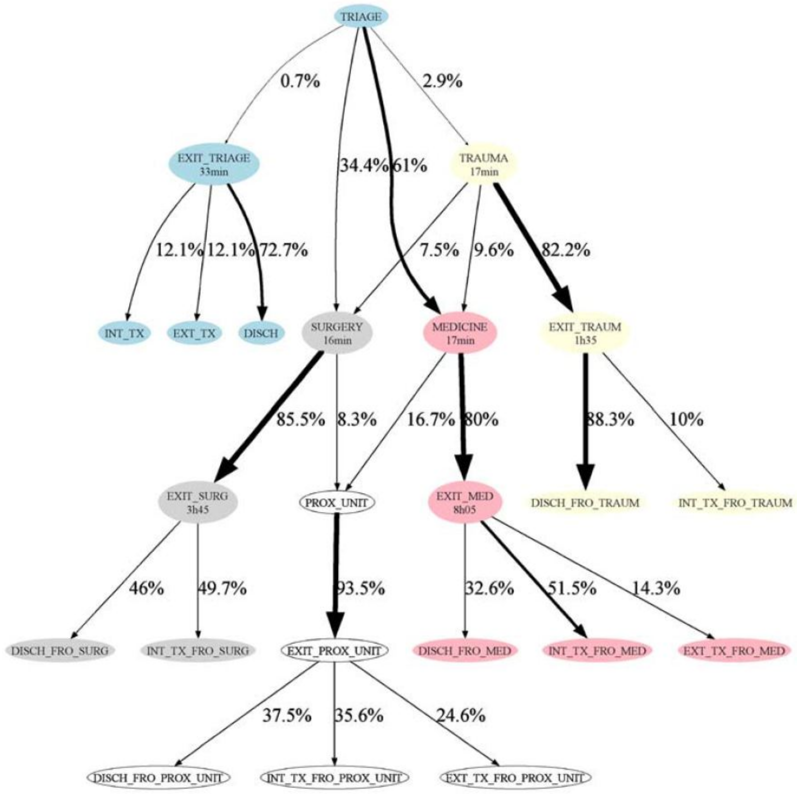

Figure 4.7: GraphViz graph resulting of the study about the elderly patients in the emergency department

prove the management of the equipment and the staff schedule. They were only focused on patients over 75 years old and their method consisted, after extracting data from the emergency department and the medico-economic database and cleaning, in doing some statistical operations in order to characterize the population studied. They could then compare different distributions of patients over time.

After this phase of data analysis, they created a model of patient pathways through the emergency department. This was done with the *GraphViz*[3] tool and an example of result graph is the Figure 4.7.

This study helped by providing a multifaceted and complete view with which physicians and nurses could better anticipate the behavior of 75+ year old patients.

The next article, "*Graphical representation of the comprehensive patient flow through the Hospital*", was written by Emmanuel Chazard and Régis Beuscart. They try to know how we can represent the patient flow going through the hospital. It is not only focused on the emergency department but on every departments of the hospital. By querying data and generating graphics, different

[3] `http://www.graphviz.org/`

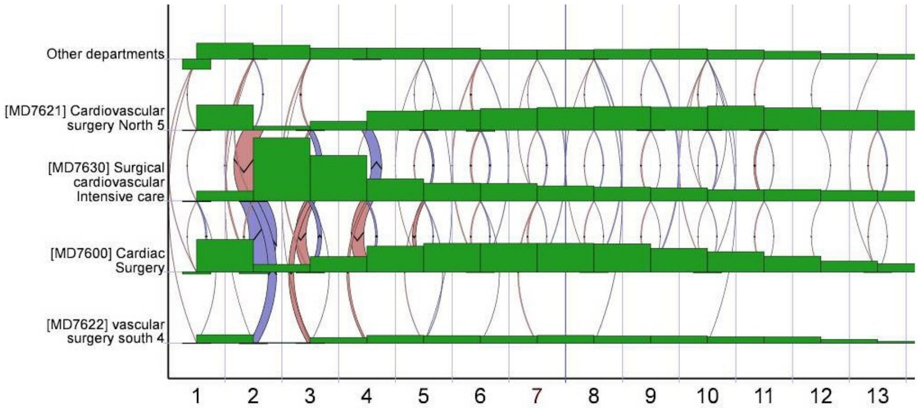

Figure 4.8: Graphical representation of the patient flow through hospital departments

patients pathways graphs are created and shown to the user. An example of such result can be seen in Figure 4.8 where the `X` axis represents the time in days and the `Y` axis represents the different departments in the hospital. The main interpretation of this graph is that "*Most of patients going through MD7630 come from MDs 7621, 7600 and 7622 the day after admittance, stay there a few days and return to those MDs for a quite long duration*". It will help the staff and management to understand how the flow of patients behaves.

With the visualization tool we have created, we had the same idea that what was shown above, namely enhance the understanding of patient flows in the emergency department and provide a tool allowing the user to clearly and quickly get a representation of these flows.

4.3 In-depth problem specification

In the previous chapters, we defined the context. We also explained the typical problems in the emergency departments. Furthermore, we presented two ways, the simulation and the visualization, that can be used to help solve these problems. For this reason, we introduced some other case studies also aiming to find a solution for the wait times issues.

In this section, we will precisely define what are the goals of this project and how we employed the two methods to achieve these goals.

4.3.1 The purpose of the project

We already briefly introduced the goals of this Master's Thesis at the end of subsection 2.1.2. We said we hope to have an impact on the effectiveness, the patient-centered and the timeliness qualities of the health care. To this end, we think that having more data about the patient flow and that giving to the medical staff more information, will help to find solutions mainly in order to reduce wait times in emergency departments. Thereby we will also cover the human side since it is the patients who will be the first to feel the beneficial reduction of the wait times.

Firstly, it is necessary to fully understand the domain in which we are working, namely the emergency departments in Canada. We already presented this quite complex domain in the previous chapters.

Secondly, to have an impact on the emergency department wait times necessitates to gather information with which we can make decisions on what to measure and what to model. Information such as:

- The number of patients arriving and the reason for their visit.
- When people access emergency department services.
- What are the resources and what is their schedule and/or usage percentage (for machines).
- Information about the behavior, decisions, needs and obligations of the care team.

Thirdly, with these information we will build a simulation model and a visualization tool to be able to:

- Discover where the wait times are the highest.
- Explain the reasons behind high wait times and their impact on the quality of care.
- Discover which factors contribute to what kinds of delays.
- Test and analyze hypothesis to understand why and/or how a phenomenon occurs.
- Discover potential bottlenecks.
- Perform what-if analysis and offer a feedback of new policies that might be implemented (*Decision Support*).

We now detail what each part of this project will have an impact on. We will describe what are the goals and how we plan to achieve them using simulation and visualization.

4.3.2 The role of Simulation

We already introduced and motivated the role that the simulation will play in the previous section. In a few words, we will analyze the patient flow in emergency department to try to minimize the length of stay, to improve efficiency, and reduce the overcrowding. The simulation model will offer a convenient tool for administrators in ED to study the patient flow and test the impact of potential modifications. The input parameters of this model have to be thought to be easily tailored to a specific ED condition. In fact, the goal is to first create a simulation model that represents the typical ED patient flow and then to adapt it for our specific ED (see chapter 6).

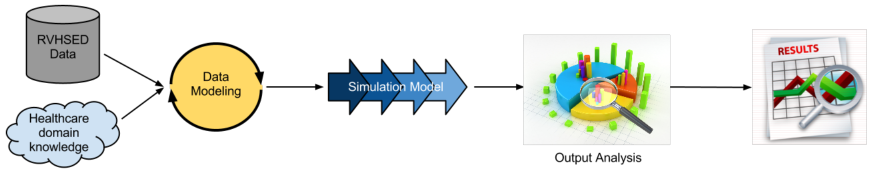

Figure 4.9: Simulation methodology overview

Figure 4.9 summarizes the methodology of the simulation part. We will first use the Rouge Valley Health System emergency department data and our knowledge about the healthcare system domain to model the data that we will need to fill our simulation model. This simulation model will then produce simulated data that we will analyze to get results.

We expect our simulation model to[4]:

- *Be adapted on the patient context and system attributes.*
- *Discover where the wait times are the highest.*
- *Discover potential bottlenecks.*
- Simulate the entire patient flow process including nurses and physician schedules, equipment (X-rays, etc.), rooms, etc.
- Show us, through simulation runs, great value knowledge to improve the patient flow and decrease the wait times.
- Test and analyze hypothesis to understand why and/or how a phenomenon occurs.
- Perform what-if analysis and offer a feedback of new policies that might be implemented (*Decision Support*).
- Reduce the wait times by improving the process policies.
- Be able to control the time speed and see what happens at a fine-grained level. The animation should be supported by a real-time visualization tool permitting to show how the system works in reality and not how it is supposed to.

4.3.3 The role of Visualization

The visualization part is a project that is independent from the simulation project, yet it is based on the same background and the same information as input. The main idea is to avoid the classical static view of the market dashboards (see an example in Figure 4.4) and make a more realistic and dynamic

[4]The italicized objectives are those which are common to both sub-projects.

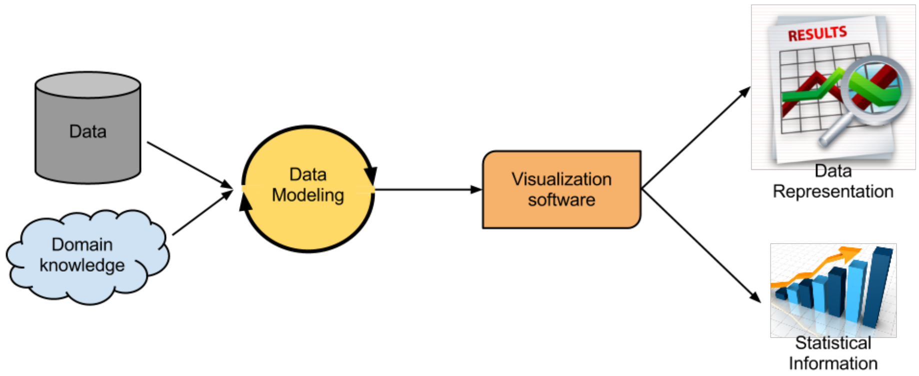

Figure 4.10: Visualization methodology overview

view of the emergency department. The motivation is to build a visualization tool useful for business and top managers, but also for physicians and nurses.

The visualization methodology used is presented by Figure 4.10. It shows that, at first we need data to work with as well as some domain knowledge. A process of data modeling is then needed in order to get a good visualization software. The results of this software is a specific data representation and statistical numbers.

In more detail for our project, the visualization tool should be able to provide an overall view of the emergency department and to show to the user at what stage of the emergency process each patient is located (while meeting privacy requirements). Everything should be done by regular (five minutes approximately but adjustable) reading of information in a database of the ED to offer a dynamic view.

Such an overview will also enable to:

- *Be adapted on the patient context and system attributes.*
- *Discover where the wait times are the highest.*
- *Discover potential bottlenecks.*
- Go back in time to show the ED state at an instant t and then allow comparison to anticipate needs in terms of personnel.
- Show overcrowding level indicators.
- Provide complementary information (such as charts) in the background.

4.4 Conclusion

In this chapter, we presented an overview of solutions that try to improve the quality of health care. We presented the two axes of solutions, namely the simulation and visualization, with which we intend to bring some answers to the problem of too high waiting times. We motivated each choice and exposed other case studies in the same field. Finally, we have precisely defined the general objectives of this Master's Thesis as well as specific objectives to each part of the project.

Road map

The next chapter of this Master's Thesis, chapter 5, will consist of a set of simulation basic concepts. This chapter can be skipped for readers having enough simulation knowledge.

Chapter 6 presents our contributions. It starts with section 6.1 developing our simulation model. After that, section 6.2 explains the implemented visualization tool. At the end, section 6.3 will presents our data analysis and processes.

Chapter 5

Simulation: Basic concepts

This chapter is an introduction to the simulation theory. It aims to give the reader a *brief overview* of the basic knowledge to have before to start a simulation project. Therefore, this chapter can be read by anybody only interested in simulation theory, or can be skipped by people already having simulation knowledge.

We will define what a simulation is. Then, we will give some directions of how a simulation model project should be conducted. After that, we will present the typical usage of simulations through an introduction to the queuing models. Finally, we will present different tools which can be used to build or to facilitate the construction of a simulation model.

This chapter is mainly inspired by the book “*Discrete-Event System Simulation*” [5].

5.1 What is simulation?

“*A* simulation *is the* imitation *of the operation of a real world process or system* over time. *Simulation involves the generation of an* artificial *history of a system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system.*

The behavior of a system as it evolves over time is studied by developing a simulation model. *The model usually takes the form of a* set of assumptions *concerning the operation of the system. The assumptions are expressed in mathematical, logical and symbolic relationships between the “entities” or “objects of interest” of the system. Once developed and validated, a model can be used to investigate a wide variety of “what-if” questions about the real world system. Potential changes to the system can first be simulated in order to predict their impact on system performance. Simulation can also be used to study systems in the design stage, before such systems are built. Thus, simulation modeling can be used both as an analysis tool for predicting the effect of changes to existing systems, and as a design tool to predict the performance of new systems.*” [5]

When are simulations appropriate?

Simulations are appropriate when people wants to study *complex* systems (a factory for instance). Also, simulations are appropriate only if the system *can be simulated* and if results *can be observed*. Results from a simulation should *bring great value knowledge* about the system or how to improve the system. To do so, simulations can be used to *try new policies* before to implement them in the real world, and see what benefits this brings. But simulations are also appropriate to *verify analytic solutions* or *to teach* people how a system works.

When are simulations not appropriate?

In contrast, simulations are inappropriate when studying *simple* systems or problems which can *be solved by common sense or analytically*. It is also inappropriate when the cost to build the simulation model and to perform the study is *too expensive* and/or more expensive than implement new policies directly into the real system. Performing simulations when *no data is available* or not in sufficient quantity should also be avoided. Also, simulations are not magic solutions. Overestimate the power of simulation by having *too high objectives* or by trying to simulate *too complex systems* (human behavior for instance) can conduct the project to a failure.

Advantages of simulation

The main advantages have been presented in section 4.3. However, simulations offer another advantage we did not present in our objectives. Indeed, simulations allow to implement and monitor more *checkpoints* than in the real process. Therefore, a simulation model offers greater monitoring and more statistical analysis possibilities.

Disadvantages of simulation

The disadvantages of simulation are due to the underestimation of the difficulty of building a good simulation model. It requires knowledge that include: system modeling, data modeling, programming, statistics, stochastic processes, etc. Before trying to build a simulation model, the modeler must ensure she has the basic knowledge to conduct such a study.

The goal of this section is not to introduce the reader to such theories but to give guidelines of how a simulation project should be conducted.

Also, being able to interpret the results to extract valuable information is another must-have skill.

Finally, the last disadvantages of simulations are that it is time-consuming and costly. A project manager may decide to not allocate some analysts on a simulation project if there is not enough time or money to perform it.

Definition of the system boundary

It is important, when building simulation models, to be able to decide what will be part of the system, and what will be out of its scope. The system boundary is the limit *between the system and its environment*. To define this boundary, a good level of abstraction is also necessary.

For instance, the system can be an emergency department including patients, physicians, nurses, beds, etc. And the environment, outside the system boundary, would be the ambulance network management or the medicine supply management.

Component of a system

"To understand and analyze a system, a number of terms need to be defined [5]:

- *An entity is an object of interest in the system.* Example: a patient.
- *An attribute is a property of an entity.* Example: the patient arrival time.
- *An activity represents a time period of specified length.* Example: the triage.
- *The state of a system is defined to be that collection of variables necessary to describe the system at any time, relative to the objectives of the study.* Examples: number of patients in the emergency department, number of nurses, number of occupied beds, etc.
- *An event is defined as an instantaneous occurrence that might change the state of the system.* Example: a patient's arrival.
- *The term endogenous is used to describe activities and events occurring within a system (e.g., completion of service).*
- *The term exogenous is used to describe activities and events in the environment that affect the system (e.g., order arrival)."*

Discrete or continuous

We can divide system into two categories: discrete or continuous.

"A discrete *system is one in which the state variable(s) change only at a discrete set of points in time. e.g., Bank: The state variable, the number of customers in the bank, changes only when a customer arrives or when the service provided a customer is completed.*

A continuous *system is one in which the state variable(s) change continuously over time. e,g., the head of water behind a dam." [5]*

Types of simulation models

"Simulation models may be further classified as being static or dynamic, deterministic or stochastic.

Static simulation model, sometimes called a Monte Carlo simulation, represents a system at a particular point in time. Dynamic simulation model represents systems as they change over time (e.g., The simulation of a bank from 9:00 A.M. to 4:00 P.M. is an example of a dynamic simulation).

Simulation models that contain no random variables are classified as deterministic. Deterministic models have a known set of inputs, which will result in a unique set of outputs. e.g., Deterministic arrivals would occur at a dentist's office if all patients arrived at the scheduled appointment time.

A stochastic simulation model has one or more random variables as inputs. Random inputs lead to random outputs. Since the outputs are random, they can be considered only as estimates of the true characteristics of a model. The simulation of a bank would usually involve random inter-arrival times and random service times. In a stochastic simulation, the output measures the average number of people waiting, the average waiting time of a customer-must be treated as statistical estimates of the true characteristics of the system." [5]

5.2 Building a simulation model

Building a simulation is not an easy task that anybody can do. It is a complicated activity which can not be conducted without a minimum of preparation and without following these steps: (based on [40, chapter 1])

1. **Problem analysis and information collection.** "*In order to facilitate a solution, the analyst first gathers structural information that bears on the problem, and represents it conveniently. This activity includes the identification of input parameters, performance measures of interest, relationships among parameters and variables, rules governing the operation of system components, and so on. The information is then represented as logic flow diagrams, hierarchy trees, narrative, or any other convenient means of representation. Once sufficient information on the underlying system is gathered, the problem can be analyzed and a solution mapped out.*"

2. **Data collection.** "*Data collection is needed for estimating model input parameters. The analyst can formulate assumptions on the distributions of random variables in the model. When data are lacking, it may still be possible to designate parameter ranges, and simulate the model for all or some input parameters in those ranges.*"

3. **Model construction.** The next step is to construct a model and to implement it using a general-purpose language (ex: C++) or a special-purpose simulation environment (ex: Arena).

4. **Model verification.** "*Verification makes sure that the model conforms to its specification and does what it is supposed to do.*"

5. **Model validation.** "*A good model fit means that a set of important performance measures, predicted by the model, match or agree reasonably with their observed counterparts in the real-life system.*" Note that validation is not possible if the system to model does not already exist.

6. **Designing and conducting simulation experiments.** Once the model is validated, the analyst can finally perform what the model was built for such as performance tests and improvements, resources optimization, "what-if" analysis,... "*To attain sufficient statistical reliability of scenario-related performance measures, each scenario is replicated and the results averaged to reduce statistical variability.*"

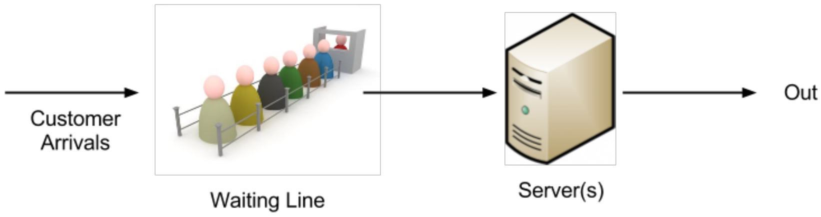

Figure 5.1: Typical queueing system

7. **Output analysis.** Output analysis is the activity to review the data generated by a simulation and compare the performance of two or more alternate system designs.

8. **Final recommendations.** "*Finally, the analyst uses the output analysis to formulate the final recommendations for the underlying systems problem.*"

These steps are reminiscent of the well-known sequential design process, namely, the *Waterfall model*. They are, theoretically, the perfect way to follow assuming a close collaboration with the members of the real system to be simulated and the input of each piece of information required to complete the simulation model.

In practice, the utopia of the Waterfall model will be quickly substituted by a more appropriate development model such as the Spiral model by repeating steps of model construction, verification, validation, and modification.

5.3 Queueing models

This section aims to provide an overview of the basics of queueing models. Simulations are often used to analyze queueing models and queues are the base of the simulation models.

Therefore, this section presents the most basic simulation model: a basic queueing system.

Key elements

Figure 5.1 shows the most basic queueing system: a customer arrival process, a queue, a server and then the exit.

A *customer* is anything that arrives in the queueing system and requires a service (a patient or an email for instance).

A *server* is any resource that provides the requested service (a physician or a secretary for instance).

We now briefly detail every aspects to know about a basic queueing system.

System capacity

The system capacity is a limit of customers waiting in the waiting line or in the system. For instance, an emergency department is not designed to accommodate 5000 patients at the same time but a limited number of them.

The modeler has to define the upper bounds (which can be infinite) while designing her queueing model.

Arrival process

The arrival process is defined as the superposition of all arrival times. It is usually defined in terms of inter-arrival times of successive customers. There are two categories of arrival: random and scheduled arrivals.

Random arrivals: inter-arrival times are usually defined using by a probability distribution like the Poisson distribution for instance.

Scheduled arrivals: inter-arrival times are constant or customers arrival times are defined using events.

Random and scheduled arrivals can be combined as scheduled arrivals plus a small random number to represent early or late arrival.

Queue behavior and discipline

"Queue behavior *refers to the actions of customers while in a queue waiting for service to begin, for example:*

- *Balk: leave when they see that the line is too long.*
- *Renege: leave after being in the line when its moving too slowly.*
- *Jockey: move from one line to a shorter line.*

Queue discipline *refers to the logical ordering of customers in a queue that determines which customer is chosen for service when a server becomes free, for example:*

- *First-in-first-out (FIFO).*
- *Last-in-first-out (LIFO).*
- *Service in random order (SIRO).*
- *Shortest processing time first (SPT).*
- *Service according to priority (PR). (e.g., type, class, priority)"*

Service times and mechanism

The service time is the time it takes for a server to complete a customer's request.

Service times may be constant or random. It is usually characterized as a sequence of independent and identically distributed random variables, e.g., an exponential or a truncated normal distribution.

Sometimes, services are identically distributed for all customers of a given type, class or priority. Customers of different types might have completely different service-time distributions.

As a queueing system is a number of service servers and interconnected queues, if servers are working in parallel the modeler has to define the mechanism of server selection. Most of the time, a customer at the head of the line takes the first available server.

Note that parallel service mechanisms are either single server (c=1), multiple server ($1 < c < \infty$), or unlimited servers (c=∞).

A self service facility is usually characterized by an unlimited number of servers.

Out

This is simply the fact of the customer releasing the server utilization, letting another customer to be served.

This can also trigger some other events like the computing of statistics like the average service time among all customers for instance.

5.4 Available tools

Now that the basic concepts are exposed, we will lost a set of different simulation tools. At the beginning, one of the first goals of this project was to use two different simulation software. As the University of Victoria already had a license for the big simulation software *Arena*, the idea was to compare it with an open-source solution.

Even if Arena is one of the most used simulation software, several other programs can be used. We then made some little evaluations of free and open-source solutions.

Arena

First, the Arena software is a discrete event simulation environment consisting of module templates, where the user builds her simulation model by placing modules using the intuitive drag-and-drop visual front (see Figure 5.2). Arena is built around `SIMAN` language constructs. For instance, a module is a high-level construct composed of several `SIMAN` blocks and elements.

For these reasons, building a model such the one presented in Figure 5.2 is quite fast and easy. After few minutes, it is possible to build a small model, run it and get a set of results.

Arena proposes more than only a "`SIMAN` interpreter"; it provides high-level modules for model building, animation of simulation runs, statistics definition and output report generation. Arena generates correct `SIMAN` code and checks the model for syntactic errors, and a large amount of initial debugging takes place automatically (initialization of a variable for example). Most errors are detected at compile time, and the rest at run time. But logical modeling errors are still the responsibility of the modeler.

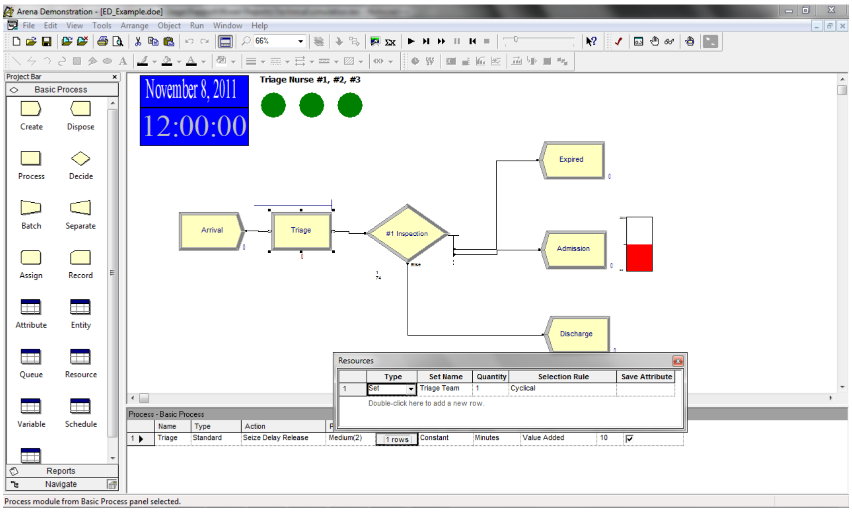

Figure 5.2: Arena environment

Adonis

Adonis was the first big opponent of Arena in the sense that it was the choice of Mr. Topaloglou. After some tests and with a little model, our conclusion was that Adonis is a good tool to model a business process as it implements the *BPMN*[1] standard. On the top of that, the development team wanted to add some "simulation artifacts". For example, there is the possibility to specify who is working on what and what is the time of work needed. The work schedule of each of the employees can also be specified. Nevertheless, the simple fact to use a special distribution as entry point, like patient arrivals, is impossible.

Another drawback of Adonis is that the documentation and the community are not very big and, badly, not very useful in some cases. At the end, we though there was a misunderstanding about the term "simulation". With Adonis the simulation tools are used to test the model of the process in order to detect some bottleneck or to optimize this process. But it will be impossible to predict the future and make some "what-if" analysis.

OMNeT++

OMNeT++ is a C++ simulation library and framework. It comes with an Eclipse-based IDE[2]. This tool is one of the first tools used to build network simulators. It is very powerful because, as it is mainly written in C++, everything could be changed, adapted in order to closely fit the needs.

However, after a little discussion and investigation, it appeared that it is very time consuming because lots of things have to be modified to fit our context, namely the health care system and emergency departments.

[1] `http://en.wikipedia.org/wiki/Business_Process_Model_and_Notation`
[2] Integrated Development Environment.

Java

This solution was not tested but it is possible to build a simulation process entirely in Java. Of course the main advantage of this solution is the total control and flexibility of what you are building. But it is thus more time consuming than any other solution and the risk of errors is increased[3].

5.5 Conclusion

In this chapter, we presented all the minimum knowledge the reader has to have to be able either to understand this Master's Thesis or to start a similar project. However, if the latter was the purpose of the reader, we recommend to study all the theories we mentioned in this chapter.

Road map

Now that the reader has a clear view of the context, of our objectives and understands the basics of the theory on which this work is based, we present the two subprojects we worked on: the simulation (section 6.1) and the visualization (section 6.2).

Following these two sections, we present what we have done with the data received from our partner, the Rouge Valley Health System, in section 6.3.

[3]As part of a simulation course we took during our internship, we had to write a simulation model in Java and, although the model was small, the number of lines of code were quite big.

Chapter 6

Contributions

This chapter constitutes the main part of this Master's Thesis. We will explain here how we developed our simulation model and the visualization tool.

Section 6.1 will detail how we conducted the simulation project. We will describe the simulation process, the various stages of the implementation and our results.

Section 6.2 will present the visualization tool. We will explain there the set of requirements, describe the program and give some pieces of precision about the coding.

Section 6.3 will present in detail the data we received from the Rouge Valley Health System. We will explain what were available and what were the issues we found during the analysis we performed.

Before going through the contributions, we want to inform the reader that this project encountered some difficulties during its development. First, we received the data one month after the beginning of the project. This fact slowed us down from the start. Second, we discovered some data quality issues and we had to work considering those issues. Third, the received data, although representing a good working opportunity, did not contain all the needed information to conduct this project. We needed more and our contact in Toronto were not always able to give us these extra information. This was due to his tight schedule or because the information we asked were too specific and required a field study. It would be wise to keep it in mind while reading this chapter.

6.1 The simulation model

Introduction

In this section, we will present in detail the simulation model that we developed during our internship at the University of Victoria.

First, we will provide an overview of our simulation model. Afterwards, we will describe the available information which were used as input of the simulation model. We then outline the different stages of the implementation, focusing on the arrival process which is critical. Once the simulation model and its implementation will have been described, we will present the parameters for the simulation run, the results and we will explain how we validated these results. Finally, before concluding, we will explain the limits of our work and propose some future work.

Before going into details, we now justify why we chose to use the Arena software instead of the other means we presented in section 5.4.

First of all, it is important to point out that the allotted time for this project was four months. And that time span included the time required to acquire the basic knowledge of the health care domain.

Therefore, we could not reinvent the wheel, we had to use a tool to go straight to the point. The first argument for Arena was that it was imposed by our supervisor as he purchased an academic license. But we have not used Arena only because it was imposed. Arena lets the user to build her first simulation model in a few minutes only and offer a lot of built-in tools facilitating the creation and the execution of simulation model. The other possibilities which we explored did not work as fast as with Arena and did not offer such a development environment.

We now present the overview of our methodology and of the simulation model.

6.1.1 Overview

Methodology overview

Figure 6.1 is a detailed version of Figure 4.9 and presents the workflow of the simulation part. We will describe it from left to right.

We first need the Rouge Valley Health System emergency department data and some health care domain knowledge to be able to start the construction of a personalized simulation model. With those information, we will perform some data analysis (subsection 6.1.2 and section 6.3) to get the parameters for filling the Arena model (subsection 6.1.3). We also design some Excel Data file that we will fill with the simulated data (section 6.1.4). Those three activites are conducted at the same time and are linked.

Once the simulation model ready to be used, we run it (subsection 6.1.4). Then, we will get two kinds of output: the Arena output and our simulated data saved in Excel files. These output represent the direct results of the simulation run. We will analyse them in order to validate our simulation model and get utilisable results.

Process overview

The process overview that we present now aims to expose the general simulation process and the difference between the existing process in the RVHS (described in subsection 3.4.2) and the simulated process. As it is a *model*, we only focused the modeling on the essential parts.

Figure 6.2 presents the simulated process. First, the patient enters in the emergency department (by himself or by ambulance). This entry point includes the patient registration together with the triage. Next, every patient is assessed.

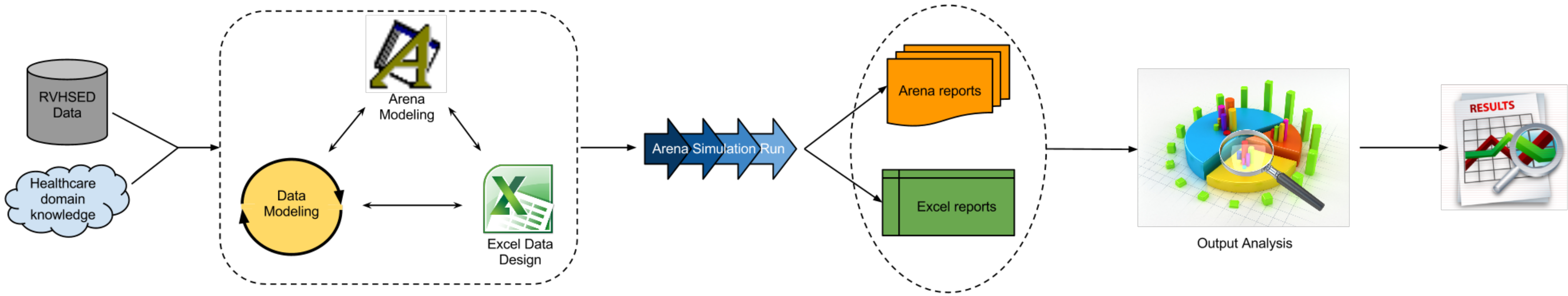

Figure 6.1: Detailed view of the approach's Input/Output

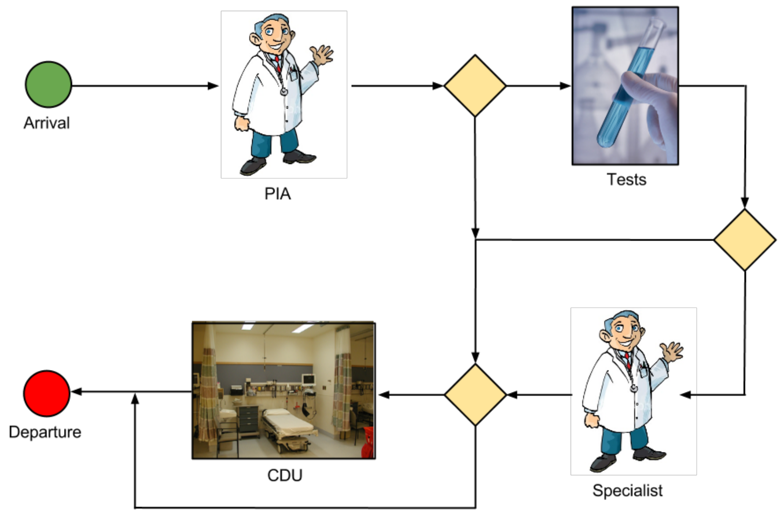

Figure 6.2: Overview of the simulated emergency department process

During the “Physician Initial Assessment” (PIA), a more thorough diagnosis than the one performed during the triage is established.

From this point, several scenarios are possible. The CTAS level V patients, with only a scratch for instance, will directly receive care or recommendations from either a nurse or a physician, before being discharged and sent back home. The other levels are likely to go through one or more tests requested by the physician.

It is also possible that a physician ask for the patient to be examined by a *specialist* (surgical cases for instance). Or the tests' results can be examined by a specialist as it is the case for radiographs.

After that, patients can be under observation for a maximum of 24 hours in the Clinical Decision Unit (CDU).

Finally, the patient will leave the emergency department either to go home, or being admitted to the medicine ward. In the case of the RVHS emergency department, every single patient admitted in the medicine ward *must* have been seen by a specialist who will sign the medicine ward entry form.

This process is very imperative. A patient will go through those main stages only once at most when, in real life, a specialist may ask for another series of tests for a patient. The reason of such a modeling will be given in the part where the implementation of the tests will be detailed.

6.1.2 Input analysis and input information

Input analysis

The input analysis is an activity where the modeler analyzes the collected data and uses it to feed the model. *Input analysis* should not be confounded with the *data analysis* in the sense that the data analysis is a *part of* the input analysis. And this data analysis should not be confounded with the one performed in subsection 6.3.2 which was more focused of the quality of the data than how to exploit the content in the model.

The following explanations are based on [40, Chapter 7], and do not aim to detail each part but to explain the main idea concealed behind, in order to inform the formal method employed for the arrival process construction.

The *input analysis* is the part of modeling where random components are modeled. In this project, the main random process is the arrival stream of the patient described in the next section. To model such a random behaviour, the input analysis is decomposed in four stages, with no obligation to strictly follow the sequence but to make several backtracking and iterations. "*If the system to be modeled already exists, then it can provide the requisite empirical data from field measurements. Otherwise, the analyst must rely on more tenuous data, including intuition, past experience with other systems, expert opinion.*"

Data collection It gathers observations of system characteristics over time. It is important to collect *sufficient* and *correct* data to avoid to build an inadequate model and then conduct to wrong simulation predictions. Therefore, caution and patience are expected to collect correct and relevant data. The sample size should be characteristic and large enough for generating the targeted statistics and no more than that. Furthermore, the collection of empirical performance measures (expected delays, uses, etc.) in the system under study is crucial to model validation.

In this project, the data collection was greatly facilitated as the data had been directly provided by Mr. Topaloglou and in a sufficient quantity (see section 6.3).

Data analysis It is the stage where the analyst will look for statistical information in the data. The statistics are often related to moments (mean, standard deviation, etc.) and/or related to distributions (histograms). These statistics are important to make the choice of a particular distribution, providing the trend of the distribution to be chosen.

Times series data modeling It is the main stage of the input analysis. It is during this phase that the analyst tries to fit a probabilistic model to empirical time series data (pairs of time and corresponding observations) collected in the first stage.

There are two categories depending on the dependency property of the times series data. If the data are independent, the analyst only has to identify the appropriate distribution and its parameters. For independent observations, Arena provides the *Input Analyzer* tool, whose main objective is to fit distributions to the given observations, doing all the analyst's work. But, if dependent observations are observed, the analyst has to fit the observations to a probability law which is much more complicated.

Times series data modeling stage of this project concerns the patient arrival process which is described hereafter.

Input information

We now detail the available information we had and that were necessary to build the simulation model.

Most of them have not been used as such in the model parameters. A statistical processing has been performed on those information in order to get percentages, average values or even to build distributions. The detail of operation is in the implementation part.

Other information has been used to model the simulation model, we can call such information "structural information".

Information from the received data From the received data, we only used the information about the emergency department. Those data allowed us to extract a lot of information for feeding the simulation model. This kind of data is very important as we want to simulate a behavior relatively close to the one in the emergency department in Toronto.

The most important information to build a model reflecting with high-fidelity an ED is definitely the dates and arrival times of the patients. With this information, we have been able to determine a mathematical distribution for our patient arrival process.

Information about how the patient is accessing the ED (walk-in arrival or ambulance arrival) allowed us to get statistics for this particular ED.

Another particularly important information is the CTAS level of each patient. This information also allowed us to get specific statistics for the RVHS emergency department and then, to have a model simulating a patient flow relatively close to the one observable in reality.

The last relevant piece of information we could extract from the received data is the status of a leaving patient. We could fill the model with the percentages of patients admitted in CDU, in the MED department (or both) or discharged.

Information from other sources Besides these precious extracted information from data we received, we had to find other information which were not recorded in these data.

To do so, we interviewed Mr. Topaloglou and searched scientific articles offering relevant information. Even if that was not specific to our emergency department, the information from articles were realistic enough to use them in our model.

The main structural information about the general operation of the ED (as described in the overview) were collected during interviews with Mr. Topaloglou.

He also provided us with the information concerning the doctors and nurses coverage, how long typically last the registration and the triage, some specifics about the specialist's call and the CDU employment.

We decided by ourselves which tests should be implemented in the simulation model and made this choice validated by Mr. Topaloglou. We gathered the information to collect statistics in a technical report of the *National Center for Health Statistics* [41].

6.1.3 Model implementation

In the previous sections we gave an overview of the simulation model and what information were necessary to fill it.

We now will detail every parts of the simulation model. We aim to give as much information as possible in order to give the reader the keys to understand our work in detail.

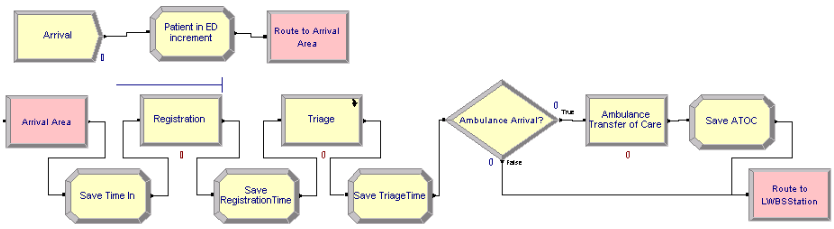

Figure 6.3: Simulation model *"areas"* example

Modeling

The steps to be followed to build a simulation model introduced in section 5.2 have not been strictly followed as the definition of the project was not complete even though the latter had already started.

To maximize the productivity considering the incremental contribution of information, steps 1 to 5 have been repeated in several cycles to build the model following an incremental process.

Consequently, there were more than one modeling phase. The first phase was to implement the standard patient flow presented in the overview. We opted for a cutting in different *"areas"*, a kind of equivalent to procedures or functions in programming, to model our simulation model (see Figure 6.3). But this model was "empty" inasmuch as no information from the database, staff schedules, assessment process time, arrival distributions, etc., were implemented yet.

The second phase was to implement the *arrival process*. A special attention was paid to this part. As it represents the entry point of the model, it has to represent the flow of patient accurately but leaves a certain degree of liberty allowing the randomness.

The third phase implemented lots of new features such as the possibility for a patient to leave the hospital without being seen by a physician (LWBS). Before to be admitted or discharged, a patient also has the possibility to move in the Clinical Decision Unit (CDU) which is limited by the number of available beds, set as 20 in the model based on an assumption. After that possibility to hold a bed in the CDU, the patient can be admitted in the hospital, and more specifically to the Medicine Ward, or be discharged. Both the CDU and the medicine ward implement a *bed management* system allowing a fixed maximum number of patient to occupy the beds. The emergency department does *not* implement such a bed management system because it is assumed there is always enough bed regardless of the number of patients since nurses can *magically* find extra beds to receive more patients[1].

The fourth and last phase of the implementation was to manage the priority of the two first CTAS levels for the PIA and through the rest of the model, to include nurses and physicians coverage, to implement a preselected set of tests for patients and to manage the specialist's call.

[1]This last remark could potentially make the reader believe that we tried to find a good excuse to not implement a bed management system within the emergency department. But that is not the case. It is *literally* how it was described to us.

As this subsection covers all the aspects of our simulations model, we decided to divide it based on the most important and relevant parts. The reader will thus have a more clear view of the model and will be able to read with more ease.

Therefore, this subsection is divided as follows:

We recommend the reader to follow the order defined above for her first reading. It will facilitate her comprehension of the details and her global view of the model.

Arrival process

The purpose of the arrival process is basically to build a specific mathematical distribution which fits the red curve presented on Figure 6.4.

By looking at the curve, we can distinguish that the flow of patient is not as intense in the morning as it is in the evening for example. Therefore, it has been decided to not try to find *one* distribution but a *set* of distributions. Observations on the curve and a recommendation of Mr. Topaloglou conducted us to first decide to divide the 24 h of a day in *6 time periods*, listed below.

1. From 00:00 to 03:59 [4 h].
2. From 04:00 to 07:59 [4 h].
3. From 08:00 to 10:59 [3 h].
4. From 11:00 to 13:59 [3 h].
5. From 14:00 to 17:59 [4 h].
6. From 18:00 to 23:59 [6 h].

Furthermore, our study of emergency departments has led us to the conclusion that a Thursday is not equivalent to a Friday in terms of number of patients and of curvature of the curves (because of partying during Friday evening for instance). Therefore, we decided to build a set of distribution *per day of the week*. It represents 42 distributions in total.

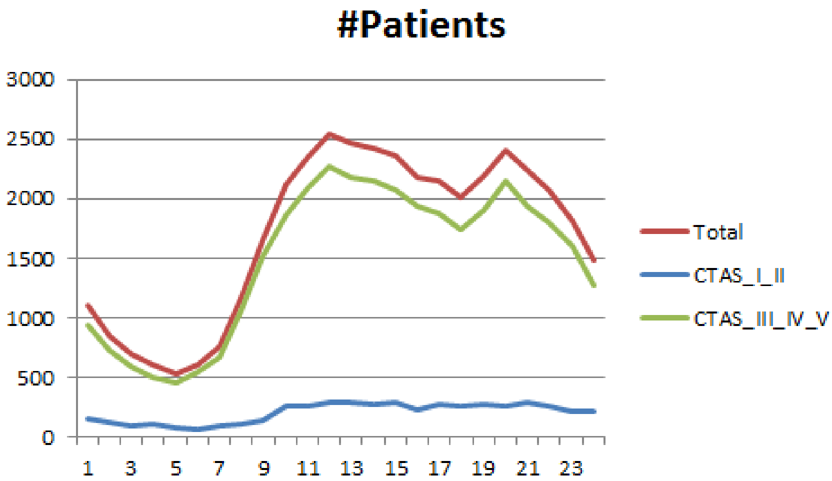

Figure 6.4: Main view of the total number of patients by arrival time

We will now detail the few stages of construction of the arrival process. Before beginning the calculation of all distributions, we have decided to focus on Monday only to test our research methodology and if good results were found, to apply the method to the rest of the days. We will explain our first methodology, show that it was a bad idea and why, and then present the second one which was more conclusive. Finally, we will detail the finalization of the arrival process development where three ideas have been explored but only one selected.

First experiment We first tried to take a single Monday which has the number of patient for a day close to the average number of patient for all Mondays. This number is 148. We looked at the data and randomly selected the 2010/10/25, where 149 patients came in. *It is important to note that we consider here the* triage instant *as the arrival time considering this is the closest information to the arrival time the database provides.*

Once the day selected, we could test our distribution maker methodology which is to take all the arrival times of the day, to classify them according to the time periods defined above and then, to calculate all the inter-arrival times. Afterwards, as we are in the case of independent arrivals, we have been able to take advantage of the available tool in Arena, the Input Analyser, and to simply let that tool calculate the six distribution for us.

Here are the six frames calculated by the Arena Input Analyser:

- Frame 1: `-0.5 + 31 * BETA(0.645, 0.595)`
- Frame 2: `-0.5 + 36 * BETA(0.213, 0.128)`
- Frame 3: `-0.5 + WEIB(7.9, 1.56)`
- Frame 4: `-0.5 + 25 * BETA(0.79, 1.51)`

– Frame 5: `-0.5 + 20 * BETA(0.605, 1.44)`

– Frame 6: `-0.5 + GAMM(6.85, 1.12)`

"`BETA`", "`GAMM`" and "`WEIB`" corresponding to a Beta, a Gamma and a Weibull distribution respectively.

Another benefit of using that tool is that the generated results also are the *code* to use in the Arena model without any modification thus avoiding any mistake.

We launched the simulation with those distributions. The first results looked good at first glance even if there were too many arrivals, 183, which is acceptable if we consider a busy day. As the Input Analyser perform the goodness-of-fit tests only on each distribution separately, we had to perform the goodness-of-fit test by ourselves for the whole distribution. We decided to perform the goodness-of-fit test using chi-square evaluation on 24 categories, one per hour. The result was catastrophic, due to a 0 in the fifth category and so, the calculus was Infinity. Even by fixing that problem with less cuttings (12 instead of 24), the result was still very bad, questioning the methodology. Thus, we looked to the graphic of this Monday and we understood our mistake. The graphic was only composed of peaks and had no similarities with the curve of the general view. As we would compare the day with the general view, which condense information of all Mondays, we had to build our distribution from the general curve, full of precious information, instead of only *one* Monday representing *one* case and specific information about that day only.

Second experiment The methodology was then completely redefined to work from the general curve. But, unfortunately, as we came from a special case—where we could find the arrival times and use the Arena Input Analyser to build our distribution—to a general case, no arrival times could be extracted.

To overcome this problem, we decided to use Poisson process (the most used in that kind of case) and to take the curve of *all Mondays* and then divide the total number of patients by time period by the total number of Mondays. There are 40 Fridays in the redefined time range of the data and 39 of each other days. Then, to define the parameter of each Poisson distribution, we took the number of minutes in the interval and divided it by the number calculated above. For example, for an interval of 4 hours and an average of 12 patients, $4*60/12 = 20$, so $P(20)$ for that interval.

This methodology considers the general curve and is still quite easy to use. We filled the model with the new distributions and launched the simulation. The first results, at first glance, looked better than before: 153 arrivals and the shape was relatively close to the general one. Only a slight drawback concerning the last frame where the trend was a little bit too "flat" instead of having first a bell shape and end in decreasing. This is why we decided to divide the last time period of 6 hours in two periods of 3 hours each, to finally have *7 time periods*.

1. From 00:00 to 03:59 [4 h].

2. From 04:00 to 07:59 [4 h].

3. From 08:00 to 10:59 [3 h].
4. From 11:00 to 13:59 [3 h].
5. From 14:00 to 17:59 [4 h].
6. From 18:00 to 20:59 [3 h].
7. From 21:00 to 23:59 [3 h].

Finalization of the arrival process Now that we know our methodology gets promising results, we have to go to the next level. We had three different ideas to finish the arrival process but only one has been used, the two others requiring too much work to be explored as we explain below.

As there are two different ways to enter into the hospital, by ambulance or walk-in, and two groups of medical gravity, CTAS I & II for the group one and CTAS III to IV for the second group, the first idea we had was to separate the arrival process into 4 distinct arrival processes, the combinations of the arrival means and the gravity groups, with its own set of distributions. 91.3% of the arrivals are walk-in arrivals which implies that the methodology explained above can be used for that kind of arrival. However, this is not the case for the ambulance arrival, the curve differing too much from the one we built the methodology for. Thus, another method should be found for the ambulance arrival. Furthermore, 7 days, 7 frames, 2 kinds of arrival and 5 CTAS levels mean we have to calculate 490 distributions in total. This methodology has been considered as too much time-consuming.

The second idea was to keep the previously computed distributions and to use only those. Therefore, we decided to use statistics. Received data show that 91.3% of patients access the emergency department as walk-in arrivals. Therefore, each patient will have 91.3% to be assigned as a walk-in arrival and then, the CTAS level will be assigned taking into account the percentage for the various levels and the types of arrival.

Because we wanted to be very specific to the data, we have thought about a third idea where we kept the same idea as the second one but decided to change the percentages every hour. But the ambulance arrival numbers were really low and even null for the CTAS group one (grouping the levels I and II) implying that the model would never assign this level. This would not be random enough. Moreover, this would require to gather and feed the model with 1680 ($7 * 24 * 2 * 5$) information which is also very time consuming.

Finally, the second option was chosen because it satisfies the general curve for each day of the week and the percentages by CTAS level are also fairly close to reality but allow some randomness.

Table 6.1 presents the final result where the lines correspond to the time frames defined above.

Time management

After discussing of *when* patients are coming into the emergency department, we have to explain *how* this is managed in Arena.

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
1	P(21.27)	P(21.72)	P(22.55)	P(20.71)	P(23.24)	P(16.63)	P(17.56)
2	P(18.87)	P(21.18)	P(23.52)	P(22.83)	P(25.13)	P(20.44)	P(19.5)
3	P(6.85)	P(7.91)	P(8.42)	P(8.14)	P(8.7)	P(9.08)	P(7.81)
4	P(5.98)	P(6.84)	P(6.8)	P(7.03)	P(6.7)	P(6.93)	P(6.31)
5	P(7.77)	P(7.65)	P(8.36)	P(8.05)	P(7.86)	P(6.76)	P(6.77)
6	P(6.81)	P(6.82)	P(7.33)	P(7.19)	P(7.78)	P(7.76)	P(6.95)
7	P(9.53)	P(9.37)	P(8.9)	P(9.11)	P(9.44)	P(9.19)	P(8.83)

Table 6.1: Arrival process distributions

Basically, almost all aspects are managed by Arena. Arena manages the simulation clock and runs the passage of time for us. It decides automatically, following the defined arrival distribution, when the next patient has to arrive. The only thing to be managed by the modeler is the switch between the different distributions.

If only one distribution is defined, it can be put in the "*create process*" (it is an Arena artifact which manages the creation of entities) parameter and Arena will do all the work. If more than one distribution is used, an *array of distributions* has to be put in the create process parameter and the switch managed by another mean. The parameter will look like '`dist_array(X)`' where '`dist_array`' is an array variable containing the distributions as values, and where '`X`' is a variable containing the index of the array. Typically, the modeler will create another "create process" which will make a new entity appears each hour (for instance), change the value of `X` and then change the distribution to be used by the patient "create process".

In our case, we check every hour if the distribution has to be changed. As we have distributions for every day of the week *and* several distributions a day, we use a two-dimensional array variable to store our arrival distributions.

Left Without Being Seen

As a reminder, a patient is considered "Left Without Being Seen" (LWBS) when she leaves the emergency department before to be assessed by a physician or when she leaves the ED against medical advice.

In our simulation model, we decided to implement only the first case. The second case has not been implemented because we did not have information about where and when patients typically leave the ED. Furthermore, the first case is the most probable one as patients have to wait a lot before to be assessed and are more likely to leave the emergency department when they not have been assessed yet.

Therefore, we placed the LWBS step between the triage and the Physician Initial Assessment. We translated this step as a probability for the patient to leave the emergency department prematurely. Moreover, we reasonably thought that walk-in patients are more likely to be declared LWBS than patients brought by ambulance and then separated the two patient categories. In the same line of thinking, we thought that patients not so ill (CTAS levels IV and V) are more likely to be LWBS than the patients who are very sick. This idea proved to be correct as no CTAS level I patient has been declared LWBS. Thus, we also

CTAS	II		III		IV		V	
Walk-in	38	0.09%	323	0.79%	283	0.69%	60	0.15%
	3951		17967		13532		1669	
Ambulance	3	0.007%	18	0.04%	8	0.02%	1	0.0025%
	825		2054		566		52	

Table 6.2: Left Without Being Seen (LWBS) patients statistics

separated the patients according to their CTAS level.

Table 6.2 shows the numbers we used to calculate the probabilities for patients to be declared LWBS. Our data contained 40754 patients records. Among those patients, 1.8% of them (734 to be precise) have been declared LWBS.

Table 6.2 must be read as follows: taking the triplet `(38, 3951, 0.09%)` on the upper left of the table for instance, this means 38 CTAS level II walk-in patients on 3951 have been declared LWBS. So, to have the probability to be declared LWBS for a CTAS level II walk-in patient, we calculate : $(38/40754 = 0.0009) * 100 = 0.09\%$. And if we sum all the probabilities in this table, we end up with 1.8% as announced before.

Concretely, when a patient arrives in the LWBS area, we check her CTAS level and whether she arrived by ambulance or not. Then, we use this information to know which probability to use for that particular patient.

Physician Initial Assessment

From this point, the priority of care providing in the emergency department must be taken into account in the simulation model. If a CTAS level I or level II patient arrives in the emergency department, she must receive immediate care. We implemented this aspect in our simulation model as it has an impact on the wait time of other patients.

In Arena, there are many ways to deal with priority queues. But to be able to preempt staff in order to take care of critical patients, we did choose to separate the patients in two categories: the first one includes CTAS level I and II patients, and the second one includes the other patients. Up to now, every patient was following the same path in our simulation model. And from this point, patients, depending of their category, will follow different paths.

The path for very sick patients will implement a preemption resource (doctor and nurses) policy and a First In First Out (FIFO) queueing policy. This means that when a very sick patient arrives in the "priority queue", staff will randomly stop their non-urgent work to take in charge the patient. Resources providing care to another very sick patient can not be preempted. The path for the other patients will also implement a FIFO queueing policing but a "`Wait`" resource policy. This simply means that if no resources are available, the patient will wait until a resource is released from somewhere else in the simulation model.

Tests

Patients in an emergency department are likely to go through a series of tests. As there are so many of different kind of tests, we decided to focus only on the main ones. After some research, it appeared that the urine sample, the blood test, the electrocardiogram, the CT scan, the X-ray and the MRI are the mains ones. Here below is the brief description of each test.

Urine sample This simple test finds urinary infections and screen for metabolic conditions, such as diabetes. It also confirms pregnancy and diagnoses dehydration.

Blood test Used to identify infections, look at blood counts, analyze blood clots, and determine electrolyte composition of bodily fluids. Doing so can determine whether or not a hospital patient is dehydrated or low on sodium or potassium. At times, a blood test will be ordered to target a specific organs or confirm diagnoses.

Electrocardiogram An EGG or EKG, or electrocardiogram, uses electrodes placed on the arms, legs, and chest to record the electrical activity of the heart. An EKG spots signs of cardiac problems, such as heart failure or irregular heart rhythm.

CT scan A CT scan, or computer tomography, uses high-dose ionized radiation to provide a three-dimensional picture of a patient. During a CT scan, a hospital patient is placed inside a machine while a X-ray tube rotates around the body. They are used to diagnose bone tumors, cancers, and fractures; as well as detect internal injuries and bleeding. CT scans can also find the exact location of an infection, tumor, or blood clot. These tests are only ordered in specific circumstances as they are expensive and may force an overexposure to radiation on the patient.

X-ray X-rays are a form of electromagnetic radiation used for medical imaging. They are often used to diagnose lung and heart disease, pneumonia, heart failure, broken bones, degenerative joint disease, and internal trauma.

MRI A magnetic resonance image uses strong magnets and radio waves to create a picture of the inside of the body. MRIs are used to find tumors, bleeding, blood vessel diseases, infections, and bone and organ damage in different areas of the body, including chest, head, bones, spine and more.

We decided then to focus only on these and made that choice validated by Mr. Topaloglou. However, no information about test duration have been found. Therefore, we decided to fix every test duration to a constant value of 20 minutes and the physician assessment (performed after each test) to 6.5 minutes.

Figure 6.5 represents the process for the tests area. The procedure is a two-time process: (1) the patient has a certain probability to pass a(nother) test; (2) percentages are distributed among the different tests and the patient will pass *one* of them. Every patient arriving at this point thus will have a certain probability to pass one (more) test and then a certain probability to pass such-and-such test.

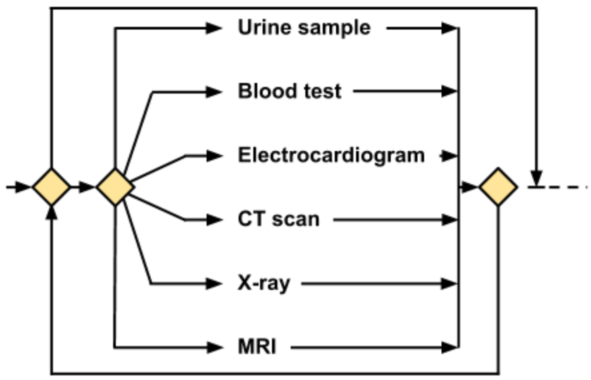

Figure 6.5: Schema of the tests management

CTAS	%
I	100
II	100
III	50
IV	30
V	10

Table 6.3: CTAS management base percentages

We have chosen the probabilities to pass a test by ourselves and then, the numbers in the Table 6.3 can be discussed. We made the assumption that CTAS level I and II patients will definitely have to pass a series of tests. CTAS level III and IV will have a fairly chance to pass some and the CTAS level V almost none.

However, in order to not make patients pass tests forever, we modeled a decremental probability system. Each time a patient passes a test, the probability for him to pass an additional test decreases by 10%. Thereby, the number of tests a patient can go through is bounded by the percentages found in Table 6.3 divided by 10. Again, 10 has been chosen by ourselves and is debatable. Note that a patient can pass the same test several times. This is intentional as it translates the fact of assessing the evolution of patients' health.

The probabilities of tests can be found in the Table 6.4. The numbers in the column A have been found in a report made by the *National Center for Health Statistics* [41]. For instance, the study says that 22.5% of all patients go through the urine sample test. But, as it is shown in the total line, if we sum all the percentages we get a number higher than 100%. To fix that issue, we reduced those numbers in base 100 to get the column B.

And as those numbers are for every CTAS levels at the same time, our decremental system has been modeled in such a way that we take the ill severity into account when the study did not.

	A	B
Urine sample	22.5%	17.67%
Blood test	39.8%	31.26%
Electrocardiogram	16.6%	13.05%
CT scan	13.9%	10.92%
X-ray	33.8%	26.55%
MRI	0.7%	0.55%
Total	127.3%	100%

Table 6.4: Tests statistics

Specialist's call

Specialists (surgeon, cardiologist, psychiatrist, orthopedic, etc.) are required in two cases: (1) if the physician request a consult; (2) to sign the medicine ward acceptance form. We decided that specialist's call is not required for an urine sample or for a blood test either. A specialist will then be called for examine results from electrocardiogram, CT scan, X-ray and MRI tests only.

Specialists are most of the time physicians working in another department of the hospital but can be external experts. As they also have busy schedules, when a specialist is required in the emergency department, it can take up to 2 hours for her to come and up to 3 hours during the night. Therefore, we modeled the patient wait time using an *exponential distribution* and a *bound* depending on the time of the day:

- From 8:00 to 20:59 → `min(EXPO(60), 120)`.
- From 21:00 to 7:59 → `min(EXPO(90), 180)`.

And we use the same trick as the one for switching arrival distributions to manage the specialist distribution shift.

Bed management

To manage the bed occupation within the emergency department, we modeled a simple variables assignment system.

Figure 6.6 represents this system that we explain now. When a patient needs a bed, we check the number of available beds. If all beds are occupied, the patient will wait for one to be released. If at least one bed is available, the patient will take it. Therefore, the number of available beds is decreased by 1. The patient will then use the full resources of bed capacity. We mean that the patient will occupy that bed and will use other resources associated with this particular bed (a medicine bed for instance). A patient could require to be monitored every hour by a nurse, for instance. Finally, when the patient does not need the bed anymore, she will be discharged from this bed (not discharged from the emergency department) and the number of available beds will increase by 1.

This simple bed management system has been used to model the CDU and the MED ward.

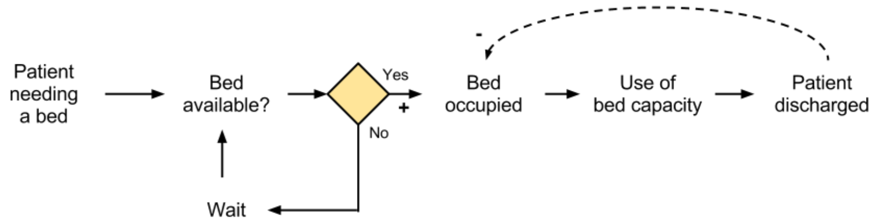

Figure 6.6: Simple bed management system schema

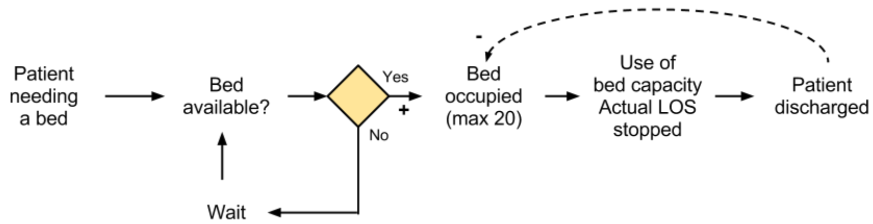

Figure 6.7: CDU bed management system schema

Clinical Decision Unit

The Clinical Decision Unit (CDU) is a special ward inside the emergency department where patient can be sent under observation for a maximum duration of 24 hours.

To be accepted in the CDU, a patient will need a bed. Therefore, the CDU implements the bed management system described above. Figure 6.7 represents precisely the CDU bed management system. It is basically the same as the one previously explained except that it precises the maximum number of beds and that the Length Of Stay (LOS) for the patient is not recorded. Every minutes spent in the CDU does not count as a minute spent in the ED.

We have chosen 20 beds by ourselves as no specific number were provided. Therefore, 20 can be discussed.

For how long a patient stays in the CDU, we used the numbers in Table 6.5 with a *triangular* distribution. For this time, we only separated patients according to their CTAS level as only the ill severity matters and not the arrival mean.

Please note that we extracted those information from our database with some restrictions: we only considered in our request the CDULOS between 1 and 1440. 1440 minutes being equivalent to 24 hours. Other information have not been taken into account as it is considered as issues in the data.

Concerning the admission, we once again use probabilities for patients to be admitted in the CDU. We separated patients according to their CTAS level and Table 6.6 shows the information we used to calculate our probabilities and the last column contains the data we used in our simulation model.

CTAS	I	II	III	IV	V
Min	20	2	2	3	95
Mean	633	567	567	356	360
Max	1080	1439	1440	1440	1052

Table 6.5: Clinical Decision Unit (CDU) Length Of Stay (LOS) statistics

CTAS	#admitted patients	#patients	% on total	% per CTAS level
I	6	138	0.015	4.3478
II	179	4776	0.44	3.7479
III	672	20021	1.7	3.3565
IV	265	14098	0.7	1.8797
V	16	1721	0.04	0.9297

Table 6.6: Clinical Decision Unit (CDU) admission statistics

CTAS levels altogether, 1138 patients have been accepted in the CDU. It represents 2.8% of all patients.

Departure

Our simulation model implements two ways of leaving the emergency department: (1) by being discharged or (2) by being admitted into the hospital. Again, we used probabilities to decide if a patient will be admitted into the hospital or not, and once again, we separated them according to their CTAS level.

Table 6.7 contains the probabilities we entered in our simulation model. We decided to separate patients depending on if they stayed in the CDU or not. We did this because the CDU's main objective is to reduce the number of admissions in the first place. We can see that is the case for CTAS levels I and II, but is not for the other levels.

MEDicine department

Once the patient is accepted into the hospital, it is outside the emergency department bounds and should normally not be taken into account for our simulation model. However, as we explained in subsection 3.5.1, sometimes, this is the lack of beds from other departments which is the cause of a patient spending more time in the ED, waiting for a bed to be released.

The full schema of possibilities for a patient after being admitted is shown on Figure 6.8. Each blue box is a department in the hospital.

CTAS	I	II	III	IV	V
Admitted	53	714	1414	204	13
%	40.15%	15.53%	7.31%	1.48%	0.76%
CDU Admitted	1	23	104	16	1
%	16.66%	12.85%	15.48%	6.04%	6.25%

Table 6.7: Hospital admission statistics

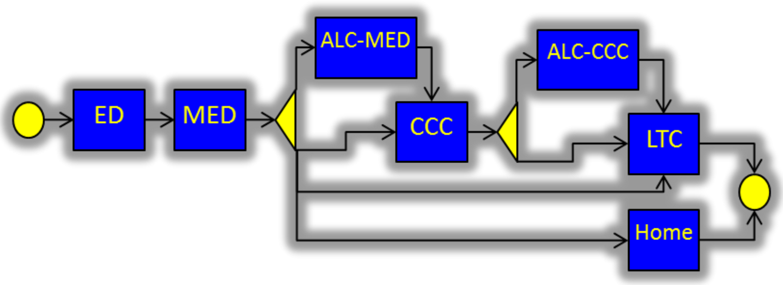

Figure 6.8: Overview of the complete path for an ED patient in the hospital

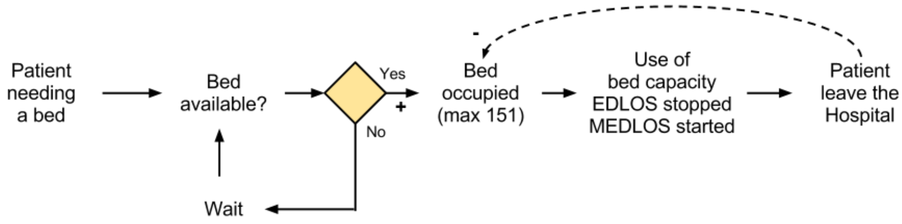

Figure 6.9: MED bed management system schema

But as implementing all possibilities is completely beyond our goal, we decided to only simulate another bed management system for that part of the hospital.

Therefore, "MED department" is actually an easy way to say "the other hospital departments". The MED department bed management system is detailed on Figure 6.9. The maximum number of beds, 151, is actually the sum of all other departments available beds.

As the patient is considered as outside the emergency department at this point, her EDLOS is not recorded anymore but a MEDLOS starts. We tried to be as close to the reality as possible for the MEDLOS. To do so, we used the Arena Input Analyser.

"*The Arena Input Analyzer functionality includes fitting a distribution to sample data. The user can specify a particular class of distributions and request the Input Analyzer to recommend associated parameters that provide the best fit. Alternatively, the user can request the Input Analyzer to recommend both the class of distributions as well as associated parameters that provide the best fit.*" [40, p 130]

Basically, all we did was to take all the MEDLOS by CTAS level, put it in the Arena Input Analyser and get the code for the distributions. Table 6.8 presents the results that the Arena Input Analyser computed for us. Please note that the distributions in Table 6.8 are in *days* and not in minutes.

6.1.4 Simulation Run & Results

Now that we detailed the implementation of the simulation model, we can present the simulation run and the results of this simulation run.

CTAS	MEDLOS distributions
I	`-0.5 + LOGN(10.4, 15)`
II	`-0.001 + EXPO(8.67)`
III	`-0.001 + GAMM(9.36, 0.96)`
IV	`-0.001 + GAMM(10.8, 0.841)`
V	`-0.5 + LOGN(7.92, 9.24)`

Table 6.8: MEDicine ward Length Of Stay (MEDLOS) distributions

First of all, we have to precise that our model clock unit is the minute. And we decided to run the simulation model over a period of *10080 minutes*, which is equivalent to *one week* exactly. We considered this simulation time as good enough to perform our first tests and get results.

Simulation output

We now come back to Figure 6.1 and detail the right side of the simulation run, the output. We can separate them in two categories: the excel reports (which will be explained thereafter) and the Arena reports. Arena natively records data during a simulation run and calculates statistics for the modeler. It produces statistics such as: entities LOS, entities overall wait times, queues wait times, number of entities waiting in queues, resources utilization. Statistics always offer the minimum, the average and the maximum of the metrics. Thus, Arena offers valuable output information about the simulation run for free.

Once the output information collected, a phase of output analysis has to be done. This is when we review all the simulated data to (1) validate the simulation model, and (2) to produce a final report and then eventually make recommendation to the stakeholders.

We now present the simulation Excel files and then, the validation.

Excel input/output

Even if Arena offers statistical results, we set that it was not enough for our purpose. Therefore, we decided to recreate in the simulation the relevant information received from the RVHS and to save it into Excel files.

To do so, we first made the *conceptual schema* of what we wanted to be recorded in the Excel files. Figure 6.11 represents this schema[2]. The complete description of this schema can be found in Appendix A and an example of an instance of the patient records generated data is in Figure 6.10.

While Arena offers only some statistics, recording each step of every patient in our simulation model allows us to learn more about our simulated data.

First, we are recording every information which are in the RVHS data that we used to understand the specifics of the emergency department and to make our statistics to fill the simulation model.

[2]This schema has been made using the data-architecture tool, DB-MAIN (`http://db-main.eu/`).

	A	B	C	D	E	F	G	H	I	J	
1	**Patient ID**	**Time In**	**Inter Arrival Time**	**Registration Time**	**Registration Duration**	**Registration Queue**	**Triage Time**	**Triage Duration**	**Triage Queue**	**Time to PIA**	**PIA I**
46	57	695	3	700	5	0	710	10	0	19.5804483172147	50.106
47	61	725	10	730	5	0	740	10	0	18.1445560630909	48.042
48	63	732	6	737	5	0	747	10	0	15.6076841098283	53.579
49	41	610	7	615	5	0	625	10	0	18.2418748923067	20
50	42	615	5	620	5	0	630	10	0	15.8432691081307	24.844
51	66	753	4	758	5	0	768	10	0	16.1915708517575	51.995
52	46	639	5	644	5	0	654	10	0	16.9261716677424	26.261
53	69	764	5	769	5	0	779	10	0	15.2764894748576	67.465
54	60	715	5	720	5	0	730	10	0	21.6794840184431	50.562
55	70	771	7	783	12	0	793	10	0	27.023163873131	72.664
56	71	778	7	783	5	1	793	10	0	21.3633957141544	73.878
57	62	726	1	731	5	0	741	10	0	19.2088011956665	52.033
58	49	658	7	663	5	0	673	10	0	15.4492536995843	34.292
59	77	814	9	819	5	0	829	10	0	18.9324408098881	66.809
60	78	820	6	825	5	0	835	10	0	16.2113768845855	70.975
61	80	829	5	834	5	0	844	10	0	21.2613739105066	78.980
62	39	593	7	598	5	0	608	10	0	15.1452273166815	23.338
63	81	837	8	842	5	0	852	10	0	18.7881812822372	84.399
64	67	757	4	763	6	0	778	15	0	27.1518398662611	72.590
65	84	855	9	860	5	0	870	10	0	15.0607358098991	98.681
66	85	863	8	868	5	0	878	10	0	19.2828070549676	94.404
67	53	677	3	683	6	0	695	12	0	23.6039799937527	44.083
68	72	783	5	788	5	0	803	15	0	22.0373731548318	75.649
69	87	880	12	885	5	0	895	10	0	16.8574402720154	101.88

Figure 6.10: Instance of an Excel file output

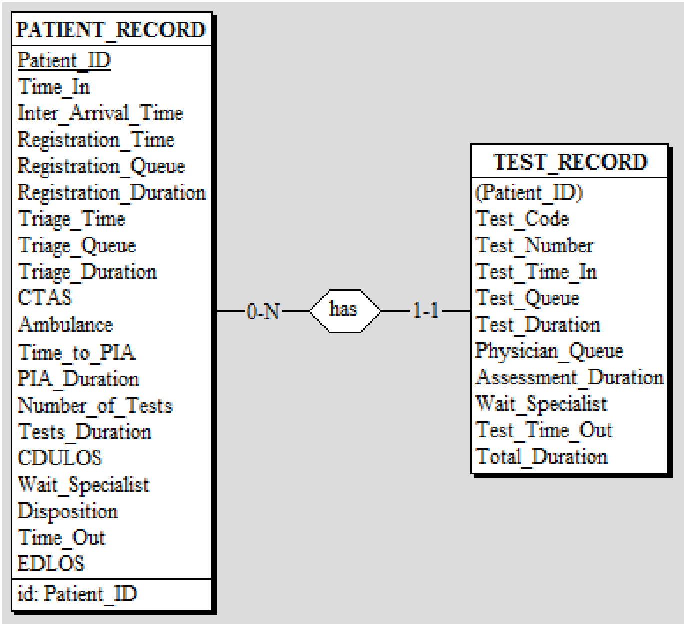

Figure 6.11: Simulation results conceptual schema

Beside those "basic information", we are recording extra information, more *checkpoints*. We first record new patient information that were not in the RVHS that we received:

- Registration queue size for each patient when they enter into it.
- Triage queue size for each patient when they enter into it.
- Number of tests taken.
- How long the tests last.
- Specialist wait time.

Furthermore, there was absolutely no information about tests performed on patients in the received data. But these information are crucial because it has a clear impact on the time spent in the emergency department and more particularly, on the patient wait times. Therefore, *all* patient tests are recorded in another Excel file. For a patient particular test we are recording:

- Which test has been performed.
- Total test duration.
- Test queue size for each patient's test when they enter into it.
- Test duration (constant: 20 minutes).
- Physician queue size for each patient's test when they enter into it.
- Assessment duration (constant: 6.5 minutes).

– Specialist wait duration for each patient's test.

Although the test duration are constant, we can retrieve information from it as we recorded other duration times. The difference between our constant value and the recorded value is actually the time the patient waited for passing her test. For instance, if we recorded 25 minutes for the test duration, it means that the patient waited for 5 minutes.

In the case where we could have more precise information to build specific test duration distributions, we should record one more value to be able to save the exact test duration and the wait time.

Validation

Goodness-of-fit testing "*A sample is assessed by a statistical test, where the null hypothesis states that the candidate distribution is a sufficiently good fit to the data, while the alternate hypothesis states that it is not.*" [40, chapter 7]

The most widely used tests are the *chi-square test*, which compares the empirical histogram density constructed from sample data to a candidate theoretical density, and the *Kolmogorov-Smirnov test*, which compares the empirical cumulative distribution function to a theoretical counterpart and only need small samples unlike the chi-square test.

Those tests do not need to be performed by the analyst who uses the Arena Input Analyser as it is implemented and computed while the distribution is calculated.

However, as we did not use the Arena Input Analyser to build our arrival process, we did perform the chi-square test to be sure that our process is valid.

To perform the test, we used the very first simulated data from the Monday only as it was for us a means of checking our modeling assumptions.

We have chosen to verify if the number of patient per time frame is valid compare to the RVHS data. We performed the test considering 5% as significance level and 6 as degree of freedom. Therefore the critical value is 12.59. Our goal here is to get an inferior value from the chi-square test compare to the critical value. The chi-square results is: 1.93. This represents a very good result. To be more confident about it, if we take 90% as significance level, the critical value becomes 2.2, which is still superior to our chi-square result. Thus, we are assured to accept the null hypothesis of a good fit at a comfortably high confidence.

We now present and validate our simulation results. We are using results from a simulation which lasts one week and the simulation run is repeated 42 times to get as much patient records as we received from Toronto. We simulated 41983 patients records, which represents an average of 143 patients par day, and 38934 test records, which represents 0.9 test per patient and translate very well the fact that most of patients in emergency departments are not serious cases (recall Figure 6.4).

We will present here the most relevant metrics only, the complete statistical report is in Appendix B.

CTAS	I	II	III	IV	V
Expected Walk-In	0.22%	9.69%	44.08%	33.2%	4.1%
Simulated Walk-In	0.18%	9.19%	43.97%	33.75%	4.28%
Difference	0.04%	0.5%	0.11%	0.55%	0.18%
Expected Ambulance	0.12%	2.02%	5.04%	1.39%	0.13%
Simulated Ambulance	0.15%	2.02%	4.94%	1.39%	0.12%
Difference	0.03%	0%	0.1%	0%	0.01%

Table 6.9: Arrival process results

	Expected	Simulated	Difference
LWBS	1.8%	0.6%	66%
Discharged	87.9%	93.46%	6.37%
CDU	2.8%	2.61%	6.79%

Table 6.10: Disposition and CDU results

Our chi-square test tested the number of patient per time frame without considering the CTAS level nor the arrival mean. Therefore, Table 6.9 presents the percentages of arrival per CTAS level and per arrival mean, and compare the expected value (from the data) to the simulated value.

The table also shows the difference between the expected value and the simulated value. We can easily see that those results are good as the absolute difference between the expected value and the simulated value never exceeds 1%.

Disposition of the patient Table 6.10 presents the results about the disposition of the patient.

We were expecting 1.8% of LWBS patients and the model simulated 0.6%. We think that the proportional difference, 66%, is too high and that we should review our calculations.

The expected discharge percentage was 87.09% and we simulated 93.46%, which makes a absolute difference of 6.37%.

CDU Table 6.10 presents the results about the CDU admissions.

We were expecting 2.8% of admission in the CDU and we simulated 2.61%, which makes a proportional difference of 6.79%.

Time to PIA The received data contained no information about the PIA. Therefore, we can not make a strict validation.

Figure 6.12 represents the results about the time to PIA. We can clearly see that the two first CTAS levels are assessed faster than the other levels, which serves our purpose very well.

The minimum time to PIA is the same for every category: 20 minutes. This timing is the minimum possible and represents the fact that the patient has been directly registered and triaged without having to wait.

We can also see that the average of all times to PIA is around 74 minutes. We can only interpret this result with our experience with the domain to say

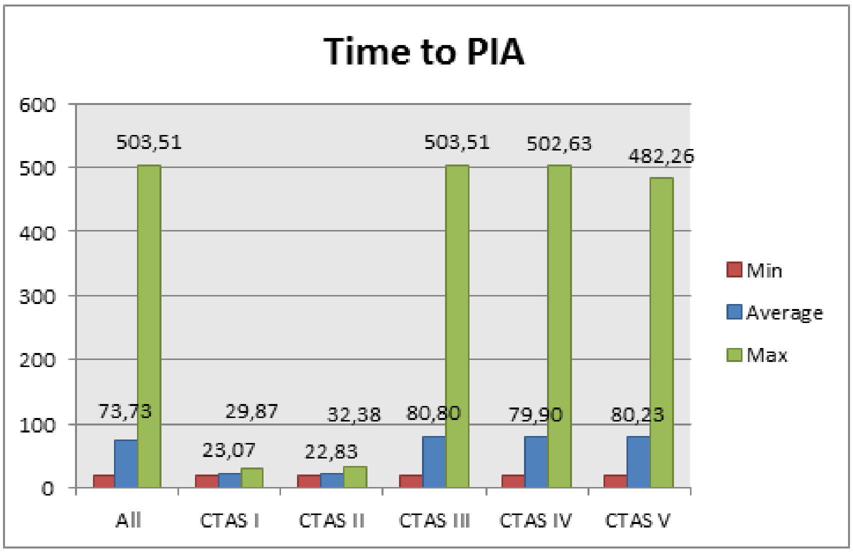

Figure 6.12: Time to PIA simulated results

that this number is a little bit too low. We were told that most of patients are assessed within two hours. Therefore, we think that this number should be around 100 minutes.

The last thing we want to point out on this figure is that the maximum is 503 minutes (8 hours 23 minutes) before to be assessed. This number may seem high but it can actually happen in a real emergency department. Because of an average of 74, we can tell that this corresponds to some isolated cases. This proves that our simulation provides a random behavior, as expected.

Specialist's call Once again, no information about the specialist were in the received data. We explained previously that the wait time for the specialist is up to two hours during the day and up to three hours during the night.

We simulated an average specialist wait time of 68.77 minutes and a maximum of three hours. We were told that the average specialist wait time should be between one and two hours. Therefore, we can say that 68.77 minutes represents a nice result.

We recorded a minimum of 0.01008703 minute, which means that the specialist was already on the spot when she was required.

EDLOS Although the received data contained information about the EDLOS, we decided to not used them to validate our simulation model. As we will explain in subsection 6.3.2, the data contained mistakes especially concerning the EDLOS. Considering we were not able to isolate the erroneous lines only and to get reliable statistics about the EDLOS of the RVHS, we preferred to not use the data and base our validation on results observations.

Figure 6.13 presents the results about the EDLOS. We see that the average length of stay in the emergency department is 210 minutes (3 hours 30 minutes). Furthermore, we can see that the EDLOS is high for the CTAS levels I and II and then decreases for the others levels. This trend represents the fact that

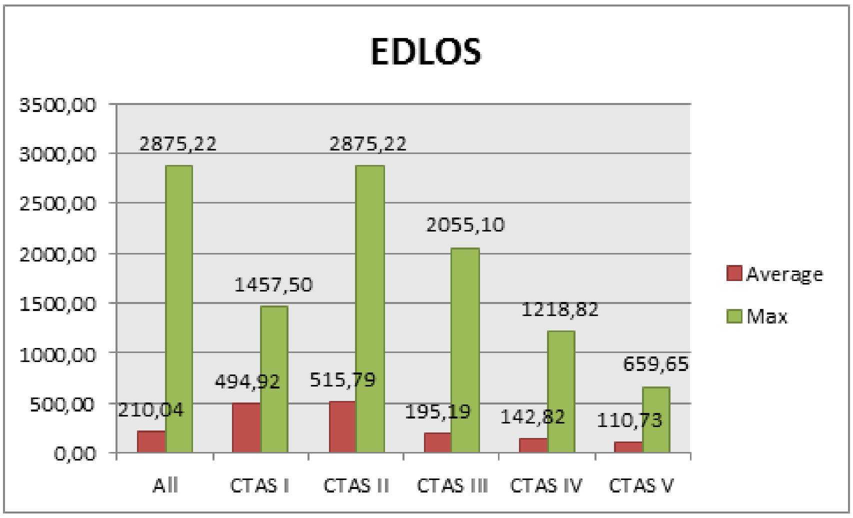

Figure 6.13: Emergency Department Length Of Stay (EDLOS) simulated results

sicker patients require more care and then stay in the ED longer. Thus, those numbers serve our purpose well.

An interesting result is the difference between the maximum for the CTAS I and the maximum for the CTAS II. We can see that this difference is about 50%, showing that even if the CTAS I patients require more care, they have the absolute priority and then are treated faster than other patients.

Medical tests results

We now detail the results about the tests. We want to recall that this part of the simulation model is based on assumptions only, and should be discussed with the managers and/or the medical staff of the RVHS.

Overview Our results show that the maximum number of patient for the a test queue is 2 and that the maximum of test duration is about 27 minutes. It means that there is obviously enough nurses assigned for the tests and that a patient will not wait long to pass her test.

However, the maximum number of patient waiting for a physician assessment is 15 and the average of assessment duration is 75 minutes. It means that patients will have to wait about 70 minutes in average before to be assessed by a physician after passing a test.

The average wait time for a specialist is 35 minutes.

Finally, the maximum total time spent for the test is about 674 minutes, ie 11 hours and 14 minutes.

CTAS proportions Figure 6.14 shows the proportions of tests by CTAS level. We can see that the resources are mainly used for the CTAS levels II and III. This is due to the high number of test passed in average (4) for the CTAS level II and because the CTAS III is actually the biggest population in the emergency department (about 48.9% against 11.2% of CTAS II).

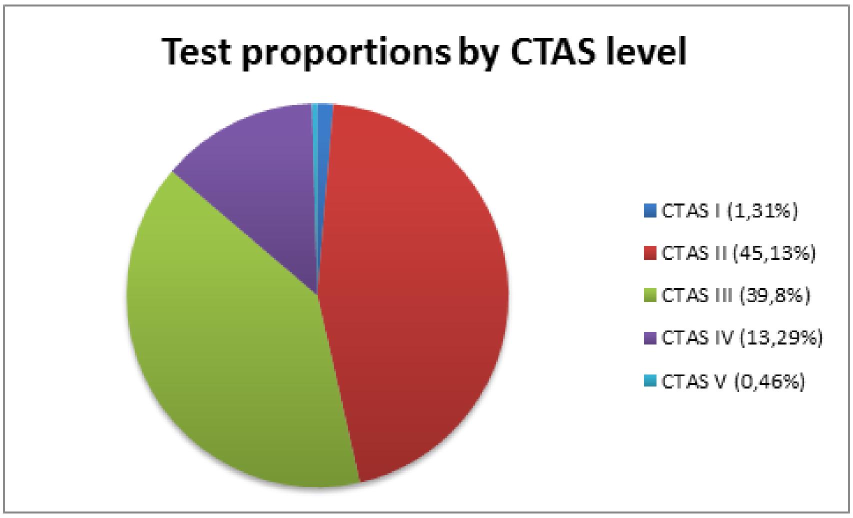

Figure 6.14: Test proportions by CTAS level

	Expected	Simulated	Difference
Urine sample	17.67%	17.81%	0.14%
Blood test	31.26%	30.97%	0.29%
Electrocardiogram	13.05%	12.97%	0.08%
CT scan	10.92%	10.9%	0.02%
X-ray	26.55%	26.83%	0.28%
MRI	0.55%	0.52%	0.03%

Table 6.11: Tests statistics results

CTAS I patients do not have a high proportion due to the very low number of very ill patients. CTAS V patients are both in small number (4.4%) and do not pass a lot of test (one maximum).

Tests percentages Table 6.11 presents the percentages of the tests. The third column shows the absolute difference between the expected value and, as for the arrival results, it never exceeds 1%.

6.1.5 Improved patient flow information

Now that we presented and validated our results, we want to highlight the new information that we were able to simulate. We decided to present it in the form of a list of new questions that can be answered by analysing our simulated data and that we could not answer before the development of this project.

Questions that can be answered

Thereafter are the new questions that can be answered by having a direct look on the simulated data:

1. How many people were waiting to be registered when a particular patient was waiting to be registered?
2. How many people were waiting to be triaged when a particular patient was waiting to be triaged?
3. How long did a particular patient wait to be assessed by a physician (PIA)?
4. How many tests did a particular patient passed?
5. How long did it take?
6. Which test did she passed?
7. How long did a particular test last?
8. How many people were waiting to be tested when a particular patient was waiting to be tested?
9. How many patients were waiting to be assessed by a physician?
10. How long a particular patient waited to be assessed by the specialist (before to be admitted)?

We now list a few questions which require additional data analysis:

1. Why did a particular patient wait more than two hours for the PIA?

   Possible answers can be found by looking at the current number of patients waiting to be assessed after their test.
2. Which CTAS level is requiring the more resources?

   We showed that it was the CTAS level II by looking at the number of tests passed by CTAS level.
3. When would it be wise to add an extra physician?

   Possible answers can be found by looking at when are the times to PIA the highest and when are the queues for the test physician assessment the highest.
4. As the blood test is the most performed test, would it be necessary to add a dedicated nurse?

   Possible answer can be found by looking at the wait times for the patient who passed that test, then relaunch the simulation with the extra nurse, and compare the new wait times with the previous ones.
5. How long in average has a patient to wait before getting her MED bed?

   The answer in our simulation results is 74 and can be found by doing an easy calculus.

6.1.6 Limits and perspectives

Now that we explained the simulation model in detail and what are its contributions, we present its limits and its perspectives.

Limits

We consider that our simulation model is not completely true as it is a representation through our own vision of the context and as we intentionally omit some aspects of the real system.

Furthermore, we can not consider our model as fully valid because we had to make some assumptions, especially for the tests, that do not represent properly the real system in place in Toronto. We can only assume our model valid considering our assumptions. Assuming we could get all the missing information and fill the model with, a strong validation must be made.

Future work

What-if analysis A lot of possibilities can be tested using a complete simulation model. We already have a practical use for the model that we did not test because it would require the active participation of our contact in Toronto which was not possible by the time of this writing. However, we describe the potential case study below.

The hospitals are getting ministry approval to operate new beds in a "short stay" unit. The purpose of a short stay unit, like the CDU, is to transfer patients form ED to short stay where they receive priority services in order to ultimately be discharged home and avoid medicine admission. As result, the ED length of stay improves, and the bed shortages in Medicine have less impact on the patient flow. Through simulation we could analyze the conditions that this model performs better than the as-is model, and be able to identify the right configuration for the model.

Despite all the work already dedicated to the arrival process, it could also be improved by modeling "*special days*" which would be important enough to have their own distribution. It includes the long weekends and the holidays in Canada: Christmas, Thanksgiving, New Year's Eve, Halloween, etc. Those days are special because of an increasing patient arrival causing a lack of rooms and potential bottlenecks, but also because the emergency department needs more staff to take care of this amount of additional patients.

Furthermore, the paper "*Modeling patient arrivals in community clinics*" [42] states that Poisson distribution is not always the best choice to make an arrival distribution. Figuring if we can make a better arrival process by using their study might be investigated in the future.

Another interesting improvement would be to implement surgery in our model. The Surgical Program in Canada is very special. Surgeons have complete freedom on which operations they want to proceed. And, as a complicate operation make them earn more money, it is current for them to arbitrarily change the schedule of the operations and decide to proceed a more complicate operation than a simple one. This behaviour pushes the delays for other patients waiting for a classical operation.

Another future work would be to get real numbers about the tests. We think that it would be nice to take into account the CTAS level to decide the percentages of the tests (instead of the ones in Table 6.4). Also, we think that implementing a dynamic percentages adaptation to the previous tests passed would permit to be closer to the reality. For the time being, a patient could pass four times through X-ray in two hours which is unlikely. Therefore, we could consider the fact that a patient already passed X-ray to decrease the probability to pass another one. We think this should make our simulation more realistic.

We now list other future work related to the simulation model:

- Add more parameters to the patient: sex, age, etc.
- Consider the sex of the patient in the bed attribution.
- Add the "travel time" from a room to another.
- 3D and closer to the reality simulation model.
- Take into account the general curve of ambulance arrival for the arrival process because the Friday one is really interesting.
- Obtain access to the RFID data to have accurate information about the localization of the patients.

6.1.7 Conclusion

In this section, we presented our simulation model. We first gave an overview of the process and detailed the input of our simulation.

Afterwards, we presented the implementation of the simulation model by explaining how were used the received data. Thereafter, we presented our simulation results and partially validated our model. We consider ourselves very satisfied with the results.

We exposed some limitations of our model and presented some future work. Before to conclude, we highlighted the new informative potential of the model.

We now present the visualization tool.

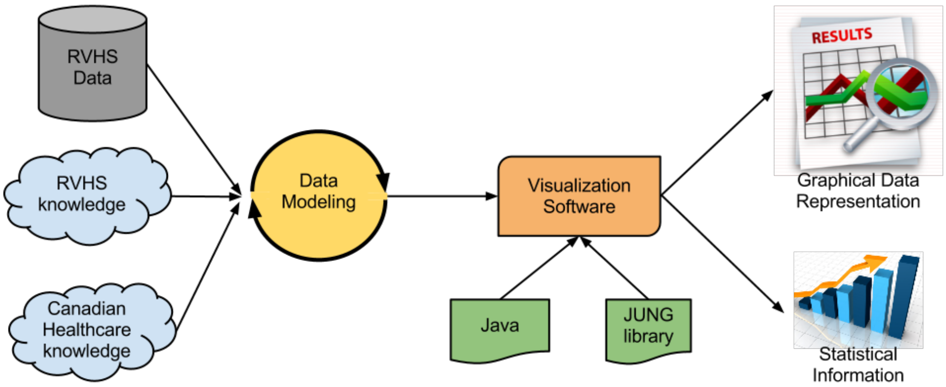

Figure 6.15: Methodology schema for our visualization tool

6.2 The visualization tool

6.2.1 Introduction

Having a visualization possibility or more is very important in a hospital and many different ways exist as that was already explained previously. Because of the dissatisfaction of the management crew in the RVHS concerning their visualization tool, our goal was to develop a new one.

As an instance of Figure 4.10, our implementation of the methodology schema is represented by Figure 6.15. This schema can help to understand how the visualization tool presented below works.

We processed some data analysis on the RVHS data with some knowledge about our partner and our specific context that is the Canadian health care system.

Once the data are analyzed, we can feed the visualization tool and we will get as output a graphical data representation of what we want to visualize and some statistical information.

This section is about the developed tool and will be structured as follows: the evolution and definition of the requirements will be explained first, with a use case diagram as output. Once the requirements are clarified, the entire program will be described with screenshots and explanations and we will see how the requirements are translated in the program. After the program description, the data location used by the program will be presented as well as the logical schema of the database. Technological choices will be then motivated. The description of the web service development and program architecture will follow. An explanation about how the whole application works will be given and an overview of the program size is provided. At the end of this section, a review will be made and some ideas will be expressed about the future of the developed visualization tool.

6.2.2 Requirements

Like most of the developed applications, we try to fully catch the stakeholders requirements in order to build the tool which totally fill the expectations. These requirements mainly came from M. Topaloglou and we used email conversations, online video conferences and a visit in the hospital in Toronto sharpen the requirements.

First idea

At the beginning of the project, the first main idea, in addition to the simulation study developed above, was to create a new management tool to better visualize the emergency department (and hospital) state. There already was a program used but it wasn't enough satisfying. This program was only composed of a table containing some statistical information such as the average number of patients coming in the ED department, the average number of waiting patients, etc[3].

The global idea that emerged was to create a tool which better renders the flow of patients going through the emergency department. To help representing this flow, we decided to use a graph representation of the emergency department and the hospital.

Final set of requirements

Once the first idea was clarified, we could quickly express the main requirement as:

> *Creating a visualization tool representing the flow of patients in the emergency department and the hospital as a graph. Each node of the graph corresponding to a step in the process.*

Figure 6.16 is the representation of these requirements using a use case diagram. In addition to the first main requirements, some more are added and are more related to the program usage.

- *Visualize ED state:* The user can have a graph representation of the emergency department. This representation should also possess the information about the number of patients at each step of the emergency department process.
- *Visualize Hospital state:* This use case is very similar to the previous one because it concerns the possibility to get a graph representation of the hospital where each step corresponds to a department. In addition to this representation, the number of patients will be displayed.
- *Get historical curve:* In order to provide a decision support tool, some historical data and charts can be accessed when possible.
- *Change date:* The user has the possibility to change the date and the time in order to visualize the state of previous days or at a different time.

[3]For privacy concerns, we are not allowed to show some captures of this program.

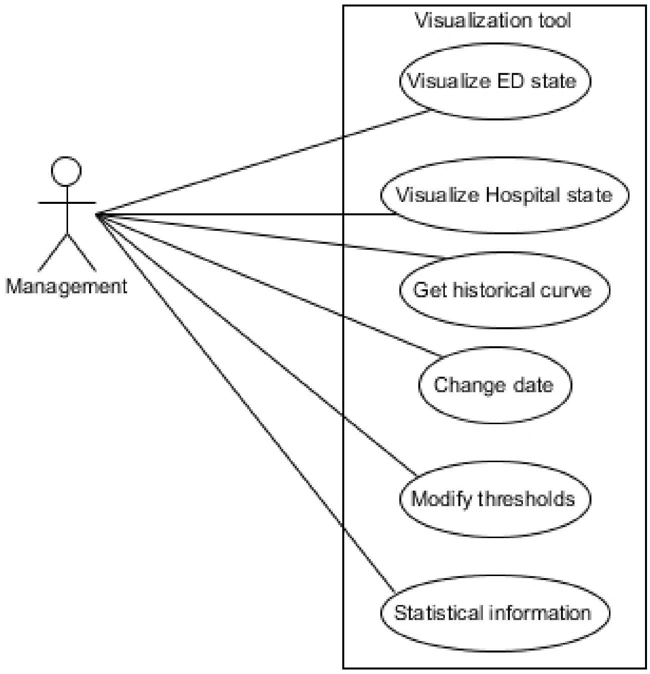

Figure 6.16: Use case diagram concerning the visualization tool

- *Get statistical information:* Some statistical information are preserved with respect to the old visualization tool already used in the RVHS.

Requirements let for future work

During a meeting with our partner, we spoke about the possibility to couple the visualization tool and the simulation model. The goal of this coupling is to minimize the number of operations and programs used by the user. This point will be explained in .

6.2.3 Program description

Now that the requirements are clearly defined, we can describe what program has been developed to meet these requirements.

This program is composed of two main tabs, one for the emergency department and the other one for the hospital. The emergency department panel will be first described and the description of the hospital panel will follow.

Before going further, it would be advise to know that some information are missing and then no information are provided to the program user.

Emergency department panel

In this panel, represented by Figure 6.17, there is the representation of the emergency department and its state. This representation is based on the provided graph present on Figure 3.1. By emergency department state we mean the number of patients at each step of the process. Each node is then the representation of a step for a patient going through this department. These steps are each described below. For consistency with the use case, the date can be changed as well as the CTAS level, impacting the numbers of patients and the statistical numbers. There is the possibility to choose to have the information only for patients with CTAS levels I, II, III or for patients with CTAS levels IV and V. This separation is chosen to distinguish critical patients and non-clinical patients. Below the graph there is a table containing some basic statistic key points such as the average length of stay, average ambulance offload time, etc.

Emergency department graph nodes

1. Walking arrival (*Walking A*): We took in consideration two ways to go in the emergency department. The first one is the walking arrival for patients going by their own means to the hospital.

2. Ambulance arrival (*Ambulance A*): The second way to reach the emergency is by ambulance. For information, a third way could be used and concerns arrivals by helicopter. This one is not represented as the RVHS is not equipped for it.

3. Triage: Once the patient is in the emergency department, the triage process is done in order to determine how critic is the patient's illness.

4. Registration (*Reg*): The registration step concerns the administrative papers. This step can be done by the family if the patient isn't able to do it.

5. Ambulance transfer of care (*ATC*): This node of the graph concerns the transfer from the ambulance staff to the emergency department staff. (We could think that this step should be place before "Triage" one but in fact, emergency department staff prefers to first triage the patient and after make the transfer of care from the ambulance staff.)

6. Non-physician initial assessment (*NPIA*): Before the patient is seen by a physician, some assessments are made by nurses in order to make a pre-diagnosis.

7. Physician initial assessment (*PIA*): This step in the emergency department flow represents the assessment made by a physician on a patient.

8. Specialist consult request (*SCR*): Sometimes, specific tests are needed and a specialist consult request is sent by the physician. This step could be problematical due to the length between the request and the arrival of the specialist.

9. Specialist consult arrival (*SCA*): The moment when the specialist is arrived in the emergency department to consult the patient.

10. Disposition: Once the work in the emergency department is done, each patient passes through the disposition step. This is an administrative step and leads to three different kinds of leaving the department.

11. Patient left: This last step is very generic because it concerns the fact of going out of the emergency department and not necessarily going out of the hospital. Patients going home or in another department are then represented at this stage.

12. Clinical decision unit out (*CDU out*): This step is a little bit special because it concerns the Clinical Decision Unit (CDU). This is a little department for patients who need one or two days in observation. After this observation, the physician will decide whether the patient can come back home or need to enter in another department in the hospital.

13. Left without being seen (*LWBS*): Some patients leave the department without saying it or without having being seen by a nurse or physician.

Statistical information

In addition to the graph representation of the emergency department and the number of patients at each step of the process, some statistical information are displayed.

- Average ED Length of Stay: Average time (in minutes) spent in the emergency department for all patients of the day.

- Average LOS Triage to Left ER: Average time (in minutes) spent in the emergency department from the triage to the disposition for all patients of the day.

- Average LOS Triage to CDU: Average time (in minutes) spent from the triage to the admission in the Critical Decision Unit for all patients of the day.

- Average LOS CDU to Left ER: Average time (in minutes) spent from the Critical Decision Unit to the exit phase of the emergency department for all patients of the day.

- Average Ambulance Offload Time: Average time (in minutes) needed to make the transfer from the ambulance staff to the emergency department nurses and physicians.

Historical curves

For nodes where a number of patients is available, the user has the possibility to get a historical chart with the number of patients of the selected step for the last 7 or 14 days. This feature is very useful in order to get the past trend of the number of patients. Figure 6.18 is an example of a historical chart that can be showed for the *Triage* step, for the last 7 days from the 7th March of 2011.

The user also has the possibility to get the curve of the day. An example of such output can be viewed on Figure 6.19. Getting this information is useful at the end of the day, when all the data are present in the database in order to render the right curve. Indeed, if no information are provided, missing information will be replaced by zeros.

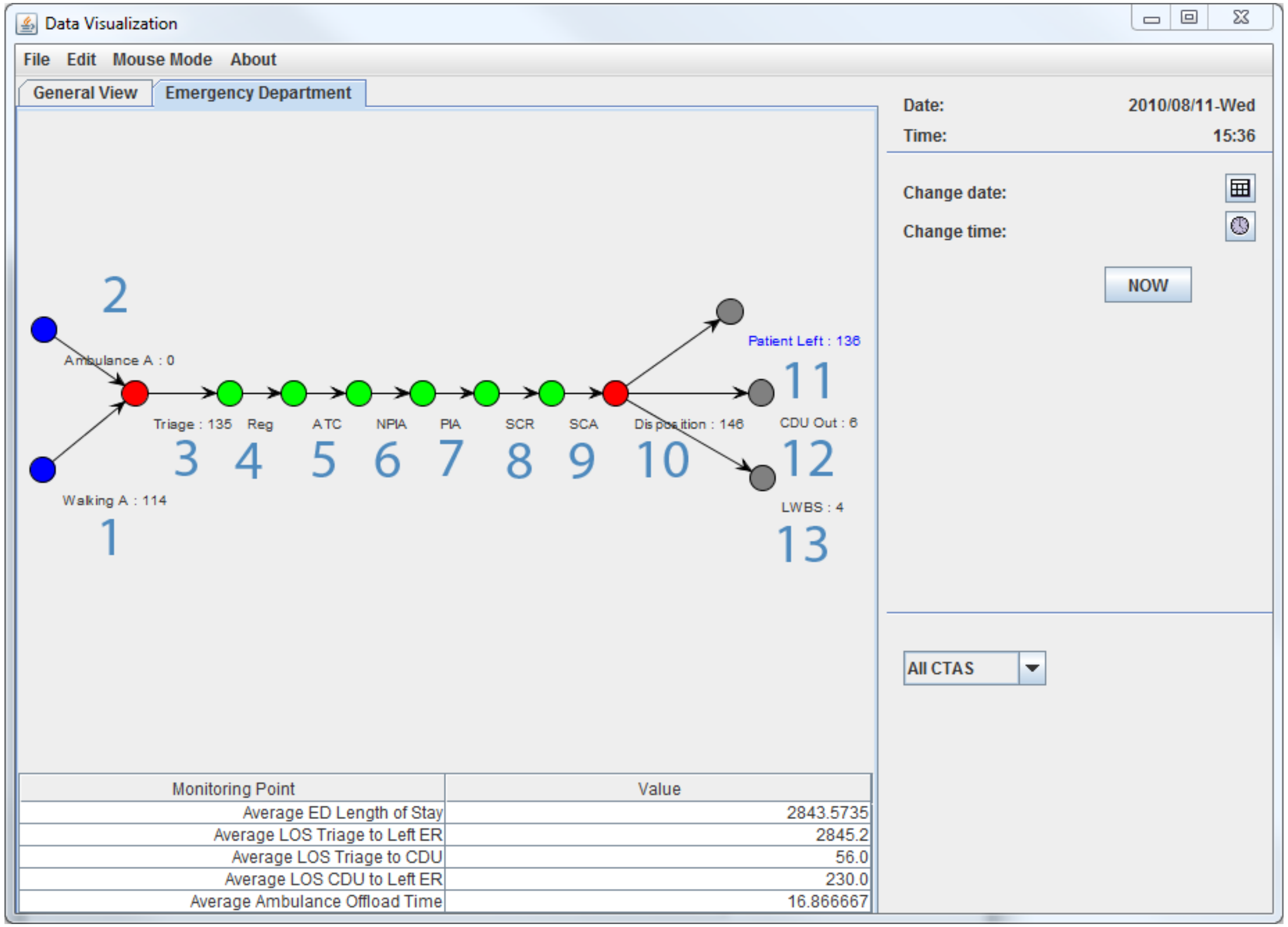

Figure 6.17: Emergency department panel screenshot

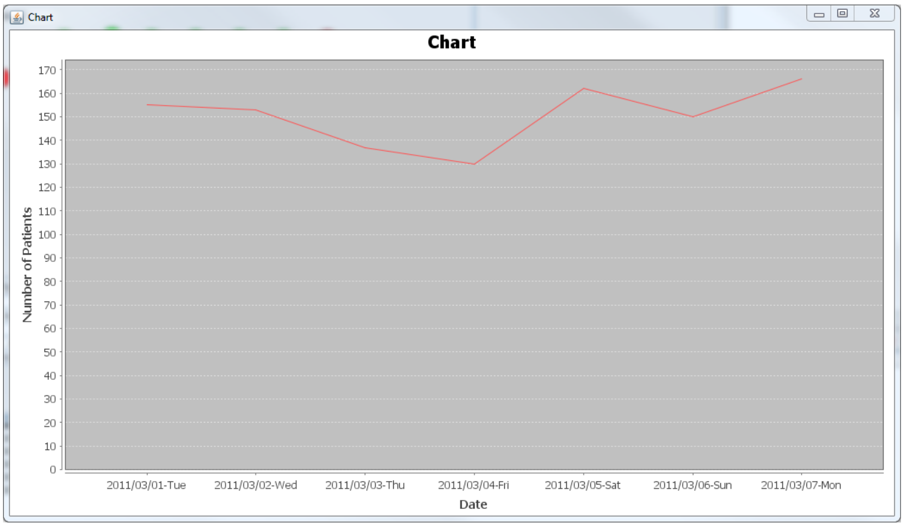

Figure 6.18: Historical data chart for *Triage* step

If we think about the mix between the visualization tool and the simulation model, the best place to see the advantage is here where missing information, replaced by zeros, could be replaced by simulated data.

Observations

We can easily spot where data are missing due to the lack of patient numbers in the emergency department panel.

Another observation is that some statistic numbers are odd. This is due to some data quality issues (with a very high negative number, we can get a negative average time).

It also appears that some patient numbers are not coherent. For example, we could get a number of patients being triaged different from the sum of the ambulance arrival and walking arrival. An explanation would be that the information is stored by hand and sometimes at the end of the day, influencing the data quality.

Finally, we can see that some nodes are colored in red or green. This is due to a threshold definition. Because of the lack of information about the thresholds for each node, we put *5-10-15* as four levels for *green-yellow-orange-red*. *Blue* and *grey* nodes are for entry and exit.

Hospital model

This panel, represented here by Figure 6.20, is the view of the hospital state. This view is based on Figure 6.8. Each node in this case represents a specific department or a patient status such as *Left Without Being Seen (LWBS)*. It is then possible to see how many patients are at each department and also how many patients are back home.

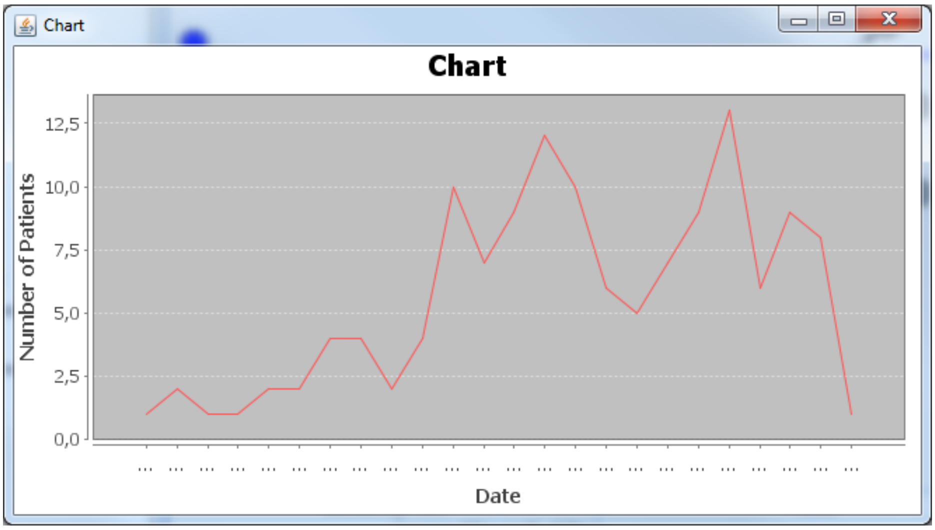

Figure 6.19: Daily curve of patients at *Triage* node

Hospital graph steps

1. Hospital entrance: Unlike the emergency department panel, there is here only one way represented for the entrance of the hospital. It encompasses both walking and ambulance arrival.

2. Emergency department: The emergency department step represents the number of patients currently in this department.

3. Medicine and surgery: The medicine and surgery departments concern patients who need more care and cannot be sent back home after their visit in the emergency department.

4. Complex Continuing Care: This step is about the higher level of illness and care.

5. Long term care: The long term care is quite explicit because it concerns patients needing a very long time of hospitalization.

6. Alternate level of care for Medicine: The alternate level of care for medicine is the term used for patients waiting a place in the complex continuing care department. These patients occupy then beds in the previous department, medicine, and can be the cause of a bigger waiting time in the emergency department due to a snowball effect.

7. Alternate level of care for Critical care: The alternate level of care for critical care works the same way as the previous one and concerns patients between the complex continuing care and the long term care departments.

8. Left without being seen: This step is the indication of the number of patients going out of the emergency department without informing anyone.

9. Home: Total number of patients coming back home from the three departments: emergency department, medicine/surgery and long term care.

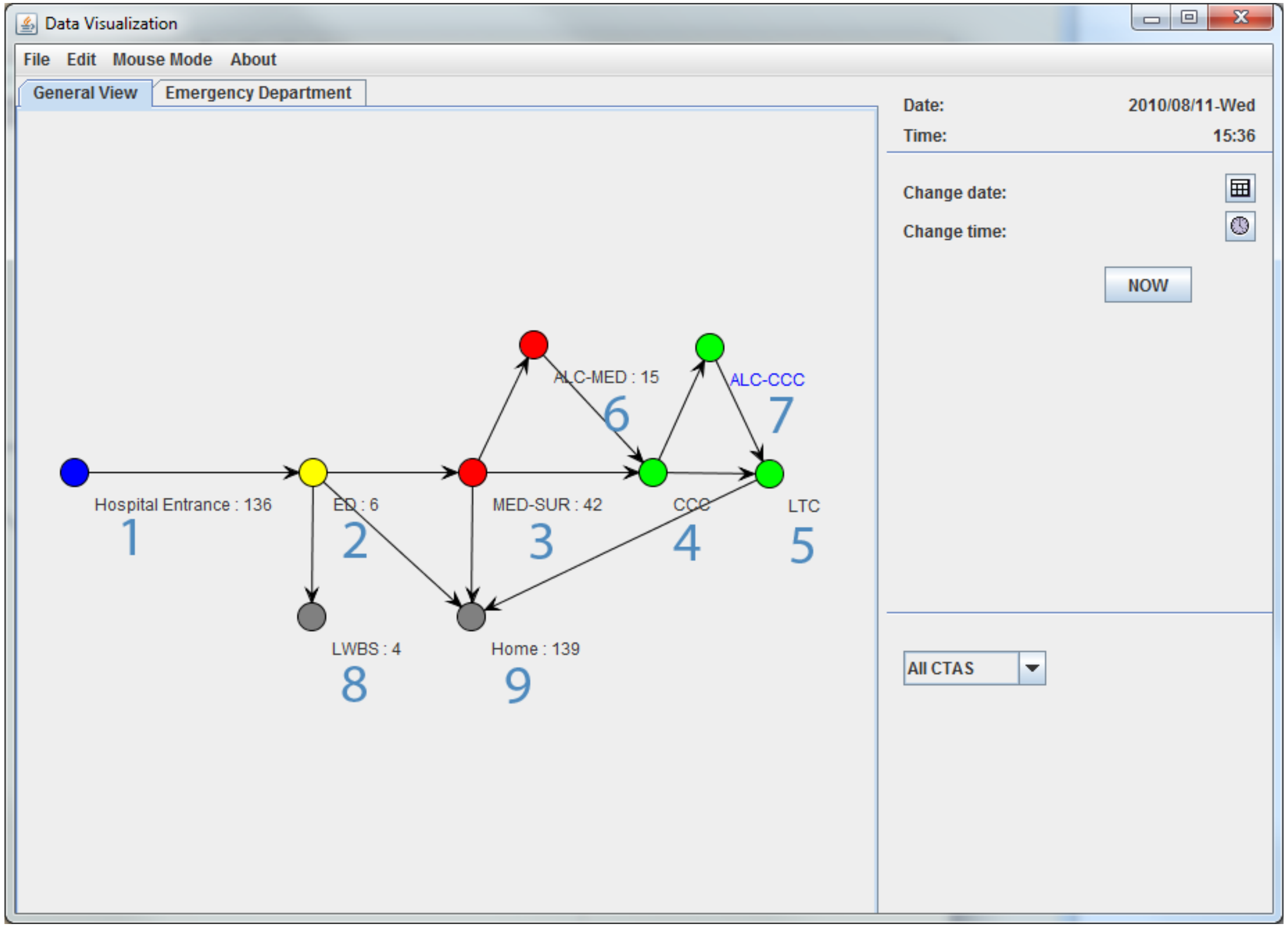

Figure 6.20: High level screenshot

Date and time modification

On both panels, the right side of the window is reserved to change the date and time of the data visualization. It allows the user to navigate in the past and analyze old states of the hospital or emergency department.

As it will be explained in section 6.3, navigating before the year 2009 is not very informative due to the low level of data quality.

CTAS level modification

Still on the right side of the windows, the user has the possibility to change the level of CTAS. The user can then choose between the information for:

- All the CTAS levels
- CTAS levels from I to III
- CTAS levels from IV to V

Observations

Despite the emergency department panel, this representation is useful to get an overall status of the hospital and of all the departments.

We also can see that some departments don't have any patient number. In this case, it is because we don't receive the access to the complete database used in the hospital. Deploying the visualization tool in this hospital should fill the blank.

As well as for the emergency department, no information were provided to determine the threshold levels. We then let *5-10-15* as default levels with the same color code.

Graph manipulation

Provided by the framework used and described below, both graphs can be modified with some basic actions such as moving nodes and zooming. This framework works with two kinds of modes for the mouse:

- Picking (default): This mode is more focused on the nodes modifications because it allows the user to pick one or more nodes and drag them.
- Transforming: This mode can be used to manipulate the entire graph by moving, rotating and flattening it.

6.2.4 Data location and extraction

RVHS data exploitation

The RVHS provided us a set of data to work with. Section 6.3 explains in detail all the operations we have processed on those data. To facilitate the programming, we migrated all the data from Excel files into a *PostegreSQL* database. Figure 6.21 corresponds to the logical schema of the database. All database accesses from the visualization tool rely on this schema. The complete documentation received about this database can be found in Appendix C.

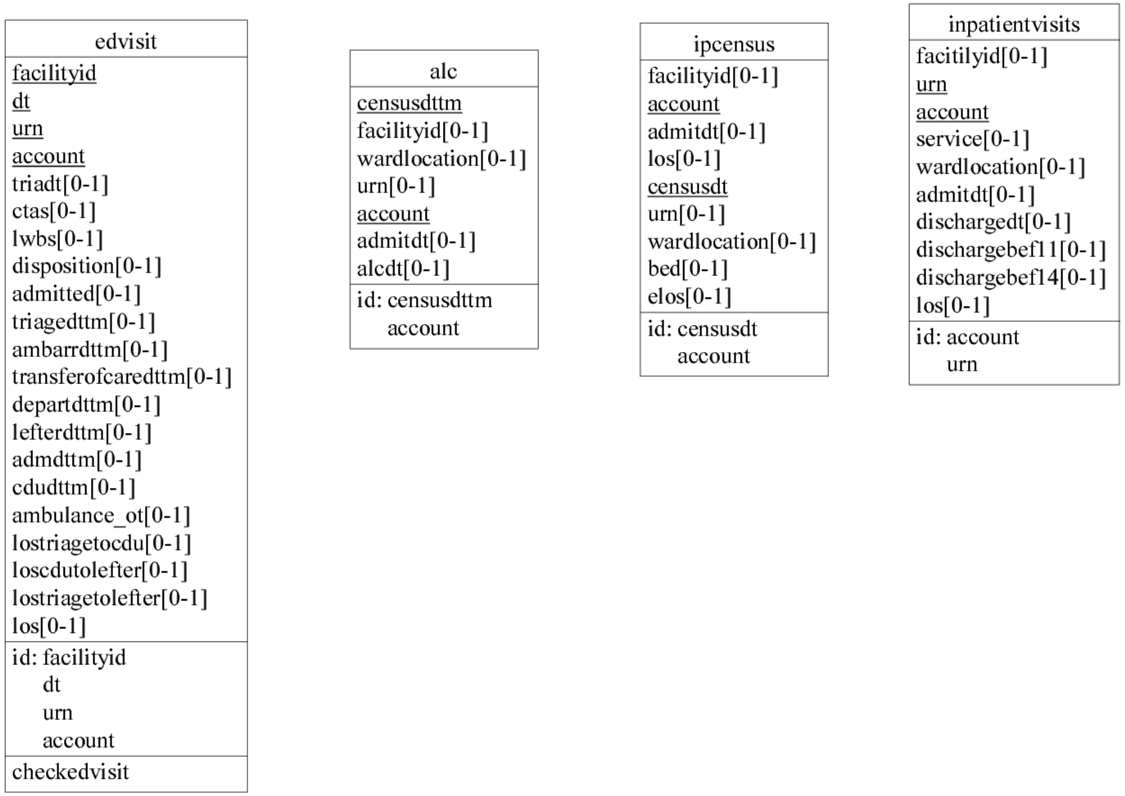

Figure 6.21: Logical schema of the database used by the visualization program

6.2.5 Program coding

Now that the program has been described, we can go into more technical aspects. A quick review of some framework possibilities will be presented as well as some technologies used to develop the application.

Framework choice motivation

Arena and Adonis *Arena* and *Adonis* can possibly be used to visualize the process in the emergency department but there is no option to link these visualization software with a database and real data. So it is impossible to have a real time visualization of what is going on. It is also a problem considering relatively big models in *Arena* because it takes a lot of time at each execution. These programs can be good in the way of representing the emergency department and hospital process, but without any link with what is really going on, they are both static.

Graphviz *Graphviz*[4] is an open source visualization software for generating graphs. The main input of this software is a file written in the `dot` language which is then processed by the *Graphviz* engine. An application of *Graphviz* was already introduced previously and Figure 4.7 is an illustration of a generated graph. However, the main drawback of *Graphviz* is the non-interaction with the generated graph, because the output is an image.

JUNG *JUNG*[5] is a software library written in Java which gives the possibility to model, analyze, visualize and manipulate data represented by a graph. As it is written in Java, it is possible to couple any *JUNG* application with a Java application. Another key point of this library is the interaction that can be added between the user and the graph. Unlike *Graphviz*, each element of the graph can be moved, clicked and so on. It is for all those elements that *JUNG* has been chosen to build the visualization software.

Other technologies

Some other possibilities can be found but were not tested nor analyzed. There are here only for the reader's curiosity.

JavaScript InfoVis Toolkit JavaScript InfoVis Toolkit[6] provides a big set of tools to create data visualization as graphs, trees or charts.

jsPlumb jsPlumb[7] is a specific tool to visually connect elements present on a web page. Like the previous one, this tool is written in JavaScript and only concerns browsers.

[4] `http://www.graphviz.org`
[5] `http://jung.sourceforge.net/`
[6] `http://thejit.org/`
[7] `http://jsplumb.org/jquery/demo.html`

Dracula Graph Library The last JavaScript based tool presented here is Dracula Graph Library[8] which provides a very easy to use library to quickly create and display interactive graphs.

Technologies used

We then took the decision to develop our visualization application using the Java programming language with the *JUNG* library. Here is a list of some patterns and other libraries used during the implementation phase of the project.

Logger In order to format the debugging messages as output and accelerate the development process, a logger has been used. We decided to use `log4j`[9] as it is widely employed and because we already used it in a lot of other projects.

MVC Model-View-Controller is the pattern used for the interaction between the GUI and the background. As the name suggests, this pattern divides the architecture in three main parts: the *View*, the *Model* and the *Controller*[10]. Basically, the *View* corresponds to the graphical user interface. The *Model* corresponds to the objects used (also referred as "*back-end*"). And the *Controller* is the entity between the *View* and *Model* to control interactions between them.

ODBC An Open Database Connectivity connection is used as a link between the Java program and the PostgreSQL database. As a bridge, it is the JDBC-ODBC (Java Database Connectivity) driver which is used.

Another solution was considered and was in the form of an Application programming interface (API) automatically generated from a schema by the *DB-Main* plugin *Deasy*[11]. This plugin can be used to produce a Java API from a conceptual schema. This API can be totally integrated into a Java application and facilitate the interaction between the program and the database as all the configuration is directly done. This solution was very promising but did not fit the expectations. Indeed, we only had to use four tables without any foreign keys between them. The use of the API was then more time consuming then the classical manner with an ODBC connection.

Dynamic information management

In order to make this visualization tool dynamic and with the information automatically changed, we used a dedicated *thread*. The role of this *thread* is to call the web service after a certain amount of time and refresh the information displayed.

Another solution would be to create a *trigger* whose purpose would be to update the information only when new data are saved in the database. This solution looks very interesting if this application is used on the real hospital database. But as we used our own database, no new information are added in this database.

[8] `http://www.graphdracula.net/`
[9] `http://logging.apache.org/log4j/1.2/`
[10] `http://en.wikipedia.org/wiki/Model%E2%80%93view%E2%80%93controller`
[11] `http://www.db-main.eu/?q=fr/node/220`

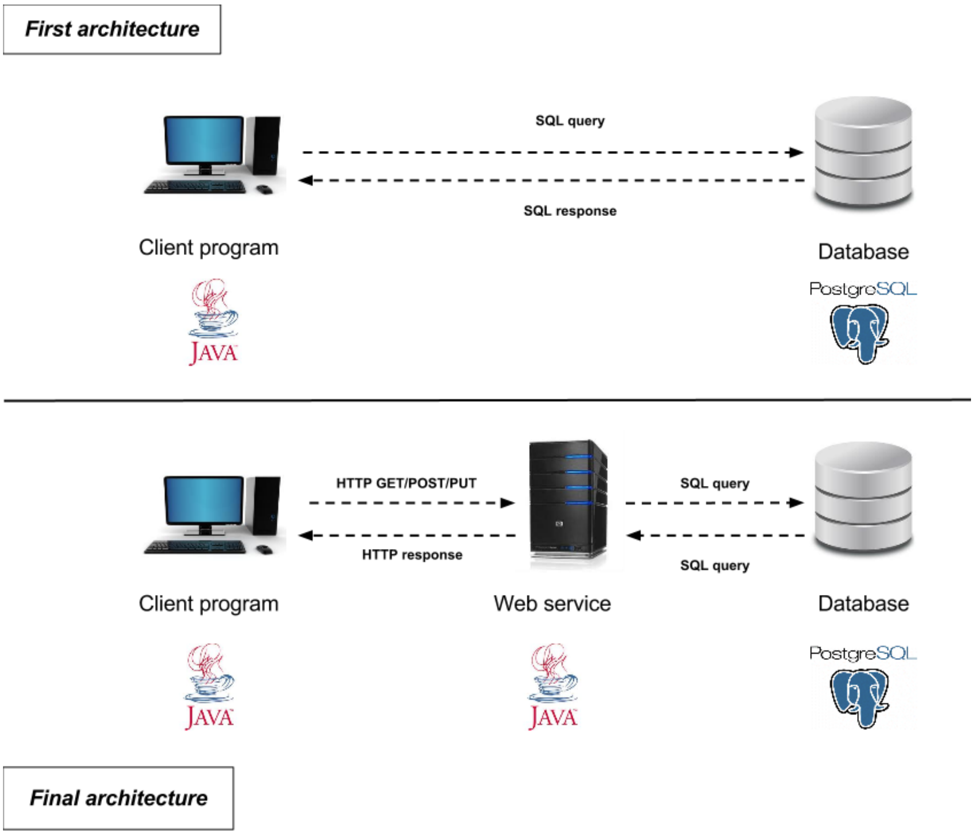

Figure 6.22: Architecture diagram of the visualization tool

6.2.6 Web service development

Motivation

With the motivation to give a better structure and scalability, we decided to extract all the database related code from the program to create a dedicated web service. This modification allows a quicker adaptation in the case of a migration from a database management system to another. It also helps the developer to change database query if needed. At the end, it provides a better cutting and separation between the graphical user interface part and the database exchanges part.

Program structure

Due to the introduction of the web service, the program structure evolved from a two components application to a three components application. This structure evolution is represented by Figure 6.22. In consequence of the use of Java as programming language, the program is platform independent. Also, with the separation introduced by the web service, only this side must be adapted in the case of another database connection.

***RESTful* and the *Restlet* framework**

To create this web service, we decided to use the *Restlet*[12] framework. After some research, it emerged that this framework was very easy to use and permitted a fast development. This framework is based on the *RESTful* paradigm for web services [43]. *"A RESTful web service (also called a RESTful web API) is a web service implemented using HTTP and the principles of* REpresentational State Transfer (REST)*. It is a collection of resources, with four defined aspects:*

- *The base URI for the web service, such as* `http://example.com/resources/`.
- *The Internet media type of the data supported by the web service. This is often XML but can be any other valid Internet media type providing that it is a valid hypertext standard.*
- *The set of operations supported by the web service using* `HTTP` *methods (e.g.,* `GET`*,* `PUT`*,* `POST`*, or* `DELETE`*).*
- *The API must be hypertext driven."* [44]

In our case then the program uses `HTTP` between the client and the web service as described by Figure 6.22. The principal method is `GET` in order to retrieve the information from the database to the client through the web service. As internet media type, there are mainly `String` values passing from one component to another. For the charts generation, *json*[13] tables are sent by the web service. *json* stands for *JavaScript Object Notation* and is "*a text-based open standard designed for human-readable data interchange. It is derived from the JavaScript scripting language for representing simple data structures and associative arrays, called objects.*" [45]

`URLs` **definition**

For each information the web service has to provide or receive, an `URL` has to be defined. Table 6.12 lists the set of `URLs` as well as the `HTTP` method(s) associated.

Due to the use of a web service separated from the client application, each `URL` defined below can be reached by a simple internet browser.

For instance, if the web service is deployed locally, reaching the address `http://localhost:8080/FlowER/ED/Out/LWBS` will give the number of patients who left the emergency department without being seen. As the result is a simple `String`, only one number will be displayed, without any form. This example is also true for the addresses with a `json` table result.

To test the `POST` and `PUT` methods, a dedicated browser plugin is required.

[12] `http://www.restlet.org/`
[13] `http://www.json.org/`

Table 6.12: `URLs` used between the client and the web service

`URL`	**Methods**	**Parameter type**	**Result type**	**Comment**
`/FlowER`	`GET`	/	`String`	Root `URL` of the web service. It is used to know whether the web service is on-line or not.
`/FlowER/ED`	/	/	/	Root `URL` of all information concerning the emergency department.
`/FlowER/ED/Triage`	`GET`	/	`String`	This `URL` concerns the number of patients for the *Triage* node in the emergency department process. For the other nodes, only the last part of the `URL` changes (`Triage`).
`/FlowER/ED/*/Chart`	`GET` and `POST`	`String`	`json` table	`URL` used to generate charts. The (*) corresponds to a node of the emergency department graph (such as `Triage` as above). It returns a `json` table with a set of patient numbers. The `PUT` method is used to specify from how many days the chart has to be generated (for instance, the client program will send a "7" to generate a chart for the last seven days).

`/FlowER/Monitoring`	/	/	/	Root `URL` of all information concerning the monitoring information. These monitoring information are some statistical numbers about different kinds of length of stay in the emergency department.
`/FlowER/Monitoring/LOS`	`GET`	/	`String`	`URL` to get the information about the average *Length Of Stay (LOS)* in the emergency department. The last part of the `URL` can be changed in order to get other statistical numbers (`LOS`).
`/FlowER/HighLevel`	/	/	/	Root `URL` of all information concerning the hospital high level view.
`/FlowER/HighLevel/MEDSUR`	`GET`	/	`String`	`URL` to get the information about the *MEDSUR* node in the hospital process. Same as the emergency department and monitoring, only the last part has to be changed to get the information for the other nodes (`MEDSUR`).
`/FlowER/CTAS`	`PUT`	/	/	`URL` used to update which CTAS level to display. This operation will affect all the `SQL` queries and the information rendered on the client side.
`/FlowER/Date`	`PUT`	`String`	/	`URL` used to update the date and time. It will also refresh all the information on the client side.

Java code sample

To show how to develop a Java web service with the *Restlet* framework, we show a little sample of the Java code from the visualization application.

```
1  public class FloweERWebService extends ServerResource {
2
3      public static void main(String[] args) throws Exception {
4
5
6          PostgreSQL.init(args[0], args[1], args[2], args[3]);
7
8          Component comp = new Component();
9          comp.getServers().add(Protocol.HTTP, 8080);
10
11         comp.getDefaultHost().attach("/FlowER", FloweERWebService.
               class);
12
13         comp.getDefaultHost().attach("/FlowER/ED",new
               EmergencyDepartment());
14         comp.getDefaultHost().attach("/FlowER/HighLevel",new
               HighLevel());
15         comp.getDefaultHost().attach("/FlowER/Monitoring", new
               MonitoringPoints());
16
17         comp.getDefaultHost().attach("/FlowER/CTAS",CTASUp.class);
18         comp.getDefaultHost().attach("/FlowER/Date",DateUp.class);
19
20         comp.start();
21
22     }
23 }
```

Listing 6.1: FlowERWebService.java

It it in that class that it is defined which `URL` is bound with with Java class. For example, line 13 shows that everything concerning the emergency department is handle by the `EmergencyDepartment` class.

6.2.7 Typical program run

Now that the program has been described and that the architecture is clear with the client side, the web service and the database, we will explain how everything works together. Figure 6.23 is an activity diagram representing the program start and allows to understand how the three components work together.

Activity diagram explanation

Thereafter is the explanation of the activity diagram. We made the assumption that the web service and database are both already running.

– **Start FlowER program:** The user starts the Java program corresponding to the client side of the application. It is usually on the form of a `jar` file like most Java programs.

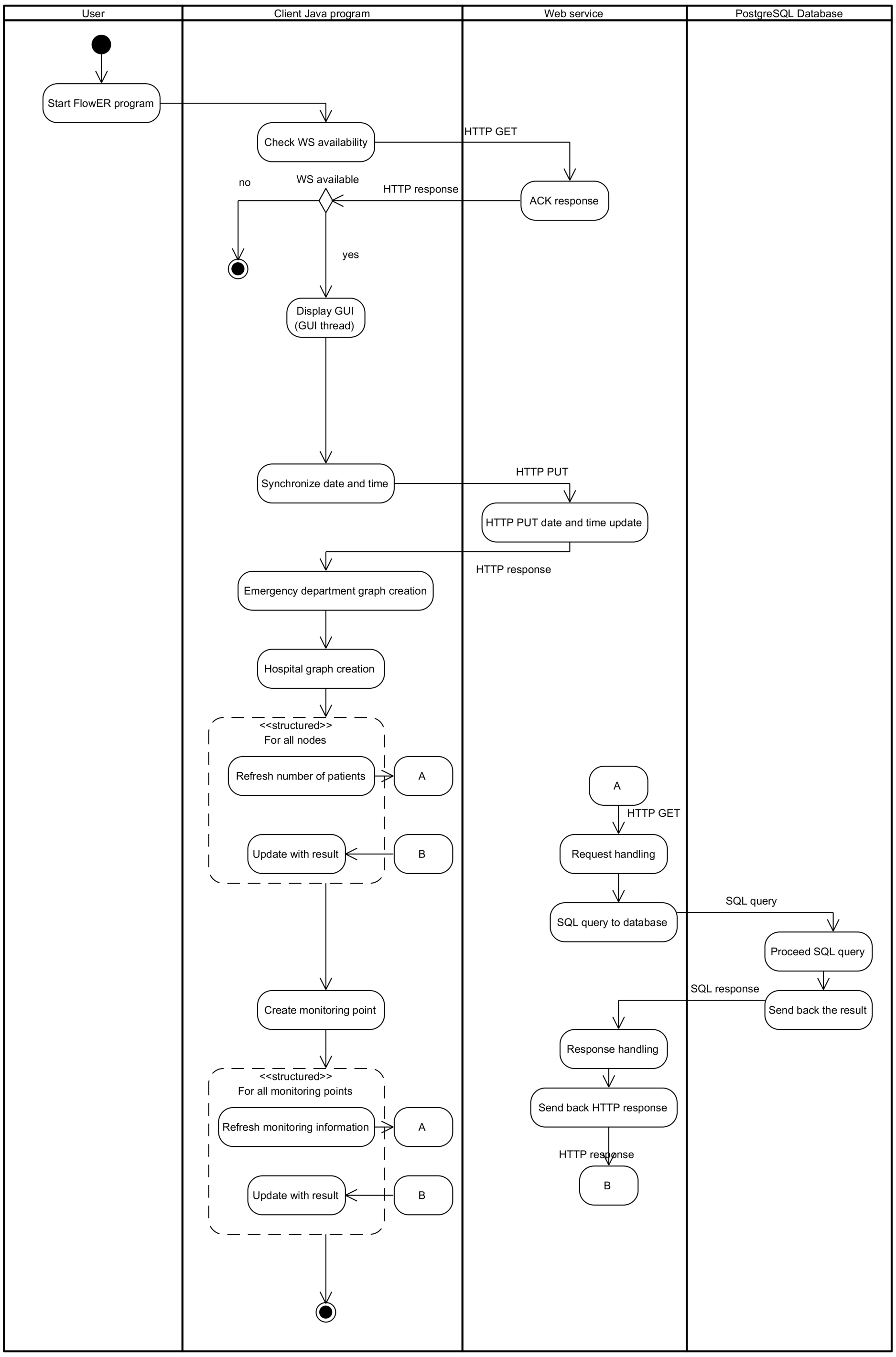

Figure 6.23: Activity diagram of the program start

– **Check WS availability:** The program will test whether the web service is available or not.

– **Synchronize date and time:** The program will, after creating the frames, synchronize the date and time with the web service. This will be done by a `HTTP PUT` method explained in Table 6.12.

– **Emergency department and hospital graph creation:** Both graph will be created and shown to the user.

– **Loop activity:** The loop activity is for the refresh of all the information concerning the number of patients. It will contact the web service to get the right information.

– **Request handling:** On the web service side, each received `HTTP GET` request will be processed in order to create the right SQL query. This query will be constructed depending on the `URL` used and the date and time.

– **Proceed SQL query:** Once the web service has created the SQL query, the database will execute it and send back the result to the web service.

– **Response handling:** The web service will receive the response from the database and will transform it into an `HTTP` response to the client application.

– **Update with result:** The client program will graphically update the information with those received from the web service.

– **Create monitoring point:** Once all the information for the emergency department graph and hospital graph are refreshed, the statistical information will be created and also refreshed. The process on the web service is the same as the update of emergency department and hospital information. It also uses `HTTP GET` methods[14]. Once all the monitoring information are refreshed, the program has finished its initialization.

6.2.8 Program analysis

To give a little overview of the visualization program size, we used the tools *SourceMonitor*[15] and *Code Analyzer*[16]. The goal of both tools is to take a *Java* program as input and provide a set of metrics about it.

Table 6.13 gives a set of metrics about the developed application. We can see that the complete program with both client and web service sides is about more than 13.000 lines of code.

6.2.9 Review & Future work

Now that the entire visualization tool has been explained in detail, we will present a little review and some ideas for the future of the application.

[14] We used "*A*" and "*B*" points in the activity diagram to let it clear and easily readable.
[15] `http://www.campwoodsw.com/sourcemonitor.html`
[16] `http://www.codeanalyzer.teel.ws/`

Component	Metric	Result
Client + Web service		
	LOC	13.179
Client side		
	LOC	10.375
	Classes	84
	Average Methods/Class	6.54
	Calls	2659
Web service side		
	LOC	2804
	Classes	52
	Average Methods/Class	2.63
	Calls	624

Table 6.13: Program metrics

Review

Building a new kind of visualization for the emergency department and the hospital is quite challenging and after some discussion with the stakeholders as well as a little bit of abstraction of the work done, we can make an evaluation of the program and see if it really meets the needs of the management staff.

Unlike the use of the simulation tool, the goal of the visualization program developed here is not to *understand* the behavior of the patients flow but to *view* it. By seeing the number of patients at the different steps of the emergency department flow or the hospital flow, the management staff can make some studies and deductions. The statistical information provided are also there to help them.

However, some limits of the application can be pointed out. A first limit is that the graph representation of the emergency department and the hospital are both static. And it is well known that it is not always the case in such entities. By building a model of the patient flow, we make an abstraction of some points and then some elements are set aside. It is always the problem to find the right compromise between simplicity/readability and completeness/realistic.

Another limit is that, due to some missing information, we do not know if we fully meet the stakeholders requirements. A big discussion should be needed in order to adjust the visualization tool.

Furthermore, due to some data quality issues, we get bizarre information with impossible values. A cleaning phase would be required to get a very clean database but it is known that having pure data without any fault is impossible.

At the end, it would also be important to make the distinction between a visualization model and a simulation model. Even if they looks very similar, each of them has specialties. In the first case we will be more focused on the graphical rendering for the user and no theoretical background is needed to understand. In the second case, a simulation model will be more detailed with parameters such as arrival distributions. Some background theoretical knowledge are here mandatory in order to understand how it is working and the results after a simulation run.

Future work

Now that all the high level considerations are done, we can point out some improvements which can be developed in order to make the program more user-friendly, powerful and useful. These future work will be divided in two parts with on the first side all the technical and development possible improvements, on the other side all the conceptual modifications.

Technical modifications

- *Statistical information enrichment:* The program provide only basic statistical numbers. Some other information can be added in the table of the emergency department panel.

- *Information storage:* Nothing has been developed to save the configuration of the program. For example, if the user change how the graph is drawn, the reload of the program will forget the modification. It is also true if the user change the threshold levels for one or more nodes.

- *GUI improvement:* The graphical user interface is very simple without any fancy rendering and some problems remain. This part of the program can be improved in order to add more possibilities for the user to get a more pleasant application to use.

- *Node modification:* Another feature that could be implemented is the fact that the user should have the possibility to change the graph such as add a node, set its parameters (name, web service url, etc) and link it with the others. With the present visualization tool, the graph is static and cannot be by adding or removing nodes.

- *Trigger creation:* As already explained, creating a *trigger* to detect when the data are modified could be very interesting to accentuate the real time side of the application.

- *Overcrowding indicator:* A last feature that could be added in the visualization tool is an overcrowding indicator, such as a "green-yellow-red light".

Conceptual modifications

- *Diagnosis consideration:* A great improvement should be to take into account the diagnosis of the patient in order to spot some typical pathways.

- *Security:* For now, there is nothing to secure the application. From the beginning of the program development, the security concern was never discussed and nothing was done in this direction. We could think of a local usage of the program, deployed on only one computer in a private and secured network but it could be a bit too idealist. It is why some security facets should be implemented. For the client side of the application, an idea should be to add some basic identifier guards with the combination login/password. Another possibility is to add a cryptosystem for the messages exchange between the client side program and the web service.

- *Real-time visualization:* As it was explained previously, only the data for a day are displayed, without any possibility to display them by time. This is a restriction due to some missing information in the database but also, it will be unreliable. Indeed, the information in the database are saved afterward and it is not totally automated. The perfect solution, already present in some hospitals, would be to like the visualization software with a *RFID system*. This will allow a real-time visualization of the patient flow and more.

6.2.10 Conclusion

In this section, we presented the developed visualization tool for the RVHS. We first described the set of requirements and their evolution. We then explained the program through its graphical user interface. Afterwards, the data location was presented and more technical information provided.

Thereafter, we presented and explained the web service development and the overall architecture of the application. Some explanations about the application initialization were presented and we finished this section with some limits elicitation and future work.

We now present the Rouge Valley Health System data.

6.3 Data

In order to achieve the project, one of the two hospitals provided us with a dataset containing *anonymized* information about *real* patients hospitalized in that hospital. The choice between the two hospitals has been made by our contact on site, Mr. Topaloglou. His choice targeted the smallest hospital. The reason of such a decision was, because of a lesser number of inpatient beds, to find more interesting behavior in the decision made by the physicians. Furthermore, the technology available in this hospital is more advanced, offering the possibility of more project evolution and expansion.

6.3.1 Data received

The dataset has been received in the form of four Microsoft Excel files, that we detail in this section. The dataset covers information which may range from 2001 to 2011, depending on the availability of the data. Indeed, lots of modifications in the recording process have been made and more should come in the future.

We decided not to use the data directly from the `xls` files, but we took the decision to exploit them through a database. We were advised to use *PostegreSQL*[17], an opensource database management system. We therefore have chosen this database management system to store our data.

During the transfer process, we kept every types employed in the initial schema. We also kept the initial data format without any modification, except for the date and the time. We chose to employ our own format in a concern of standardization between the same kind of information, and also in a concern of easiness, considering the kind of queries which would be required in the data analysis and the data extraction processes.

The formats employed are the following:

- `Date: yyyy/mo/dd-ddd`. Example: "`2011/04/12-Tue`".
- `Time: hh:mi`. Example: "`23:51`".
- `DateTime: yyyy/mm/dd-hh:mi-ddd`. Example: "`2011/04/12-23:51-Tue`".

Data exploitation

Joined with the four Excel files, a documentation file was provided, explaining briefly each column for each table (see Appendix C).

We will now detail each of the four files by giving a brief description of the content, its use in the project and its time range.

[17] `http://www.postgresql.org/`

`edvisit` "edvisit" stands for "Emergency Department Visits". This is actually the most important dataset of the project. It contains the information constituting the basis for the research and facilitates the comprehension of the behavior of the emergency department. It provides essential information to conduct a study on an emergency department such as the date and the approximate time of arrival, the degree of illness (CTAS), the length of stay (LOS), the fact and the moment whether the patient had been admitted or discharged.

The time range is from the *23rd of June 2002* to the *12th of April 2011* which could potentially constitute a significant amount of information on almost ten years but will not meet our first expectations due to recording issues.

`alc` "alc" stands for "Alternate Level of Care". This is a term used when a patient is occupying a bed in a department but must be moved in another. This occurs when there is not enough bed in the next department. Some resources are then allocated to this patient while she no longer belongs to this department [46].

This file contains one record per each patient for each day in ALC state. Because ALC has a wide definition, there can be ALC patients between the emergency department and medicine, between medicine and long term care, etc.

The time range is from the *12th of July 2010* to the *12th of April 2011* constituting nine months of data.

`inpatientvisits` This file contains inpatient records only for Medicine and Surgical services, but also includes ALC records which are not only those that are linked to Medicine and Surgical beds, but also those in other units such as Complex Continuing Care, etc.

Although the purpose was to be focused on the emergency department, we said the problem for a longer LOS in the ED might come from a lack of beds further in the chain of departments (subsection 3.5.1). Having information about the next step in that chain and take it into account by analyze and include it in the modeling process offers a larger spectrum of possibilities in future case studies.

The time range is from the *15th of May 2001* to the *11th of April 2011* constituting almost ten years of data for about `13000` entries.

`ipcensus` "ipcensus" stands for "Inpatient census". The file contains a record per patient per day which permits to go deeper in the understanding of the path taken by a patient.

The time range is from the *2nd of December 2009* to the *12th of April 2011* constituting almost sixteen months of data for about `50000` entries.

6.3.2 Analysis

In order to deeply understand the data at our disposal and to know how we can exploit them, we performed some analyzes on those data.

The conclusion has very quickly emerged: there are a lot of inconsistencies, typing errors, transpositions, missing data, redundancy and variation in spelling.

Of course, we are far away from the "*ideal world*" where data would go into the data base without any problem. The Rouge Valley Health Systems database is, as it is common in the practical world, not filled only by one application but a number of applications and by humans who have to record the data when they have time for it, between two patients or two sample analysis. In addition, the government of Canada changed more than once the legislation determining what hospitals must record about their patients resulting in a database containing legacy data of old data schemes.

The major problems

As the most important information were in the `edvisit` table, we have been focused on it. And as announced previously, the theoretical time range of this table is from the *23rd of June 2002* to the *12th of April 2012*. But, only a few entries were available from 2002 to 2007 included, making those data unusable. Thus, the years 2008, 2009 and 2010 constituted our first redefinition of the time range for `edvisit`. Each year has more or less the third of the total content.

Once we had a closer look at the data themselves, especially the column `los`, we discovered that some patients had spent more than two years in the emergency department. Which is impossible.

By looking a little bit further, we have established that 99.99% of the patients in 2008 and 71.25% for 2009 spent more than an entire week in the emergency department. More information about such data have been required but there is no correct and accurate answer for that problem; only classic assumptions like missing data fields defaulted to some value by applications, etc.

Lots of negative values have also been discovered where only positive values should be found. The explication was that the column was calculated based on a computation on two other columns and that the person who filled these column inverted them.

Finally, as the data have been delivered in the form of `xls` files, there were no `primary key`, `foreign key` or `index`. Initial primary keys have been used but no foreign key could be defined due to missing information.

Time range redefinition

Our analysis has concluded that the major problems came from the years 2008 and 2009 and then we should work on the year 2010 (only 3% of `los` bad entries for 2010).

It has been finally decided to work from the *1st of July 2010* to the *31st of March 2011* because the Canadian government's last regulation modification took effect from this date. This constitutes a period of 274 days and about `40000` lines, which is large enough to conduct a project on such a dataset[18].

[18]It still remained 2.65% of odd rows and we decided to simply ignore them when we had to extract information.

6.4 Conclusion

In this chapter, we presented what was developed for the simulation part and the visualization part. This concerns our whole contribution in the context of our Master's Thesis.

The first part develops the simulation model by presenting its different stage of development. It first describes what was the input of our simulation model, then detail the implementation. Afterwards, we presented the simulation run, our results and the validation of the model. We finished the simulation part by exposing some limits of our model and presenting some future work.

Then, the visualization tool was explained and described. Some technical information were provided as well as possible improvements for the quality of the application.

The last part of this chapter was about the data manipulation, analysis and transformation. This explains how, both visualization and simulation parts, could work with the real data provided by the RVHS.

Chapter 7

Conclusion

7.1 Summary

In chapters 2 and 3, we described how the health care system and hospitals are working. We gave more information about the eHealth definition and about the Canadian case. In particular, we saw that Canadian emergency departments wait times are too high and that health care institutions are looking for solutions.

In order to have an impact on this issue, we decided to build a simulation model and a visualization tool. The purpose of such tools is to discover which factors contribute to what kinds of delays and to explain the reasons behind high wait times and their impact on the quality of care. We completely describe our methodology in chapter 4 as well as a wide overview of the state of the art.

We then gave the reader some explanations about what is simulation and how to conduct a simulation project in chapter 5. This chapter offers the basic knowledge required to build a simulation model.

In chapter 6, we explained in detail our two tools and some information about data analysis and modeling. The section 6.1 is dedicated to the simulation model. We present there the overall simulation process, precise our input information to build and fill the simulation model. We then detailed the implementation, giving precious information about the data modeling and how we used the Rouge Valley Health System data to make our simulation model. After that, we detailed the simulation model output in terms of reports, what are our results and how we validated our model. Before to conclude the simulation section, we listed some limits about our simulation model and gave some ideas for improving the simulation model.

The section 6.2 is dedicated to the visualization tool and starts with the definition and evolution of the stakeholders requirements. The program and user interfaces description shows how these requirements are satisfied and how the developed tool looks like. A more technical part is present after with information about the programming language used as well as the different frameworks called by the program. Still in the technical part of this section, the overall program structure is described and motivated with some information about the implementation. At the end, we gave some future work, improvement to be made and a review of the application.

Finally, the last section of this chapter, section 6.3, concerns the data received. As it was said, we used some real data to work with from the RVHS and we described all the transformations and analysis made on these data. We also pointed out some problems related to these data.

7.2 Contributions

Our first contribution is the **overall description of the health care system** with a specific attention to the Canadian case. We entered in more detail for the emergency department and elicited high wait times issues and overcrowding concerns. This context definition allows us to be fully aware of the challenging problem the Canadian health care system has to tackle.

Our second contribution is the **data analysis** we performed for the *Rouge Valley Health System*, pointing some data quality issues.

The third contribution of our work is the **simulation model**. We have been able to develop a simulation model which closely simulates the patient arrival process of the RVHS. The model has been modeled to be specific to this particular emergency department and has been filled with their own historical data. In addition to simulate the RVHS data, we were able to simulate brand new information that were not available to begin with. In particular, we offer detailed information about the patients' tests and this allows us to get answers to a lot of questions about the reasons of the high wait times. Finally, our simulation model is now ready to be used for decision support by performing what-if analysis and offer a feedback of new policies that might be implemented in the emergency department.

The fourth and last contribution is the **visualization tool**. This tool takes as input the data received from the hospital and display two graphs. The first one is the representation of the emergency department, where each node is a step in the process for the patient. At each node, a number of patient is attached as well as the possibility to have some historical trends. Some statistical information are also provided. The second graph represents the hospital with an abstract view. Each node here corresponds to a department or a patient state. The number of patient is also attached at each node. This tool allows then the management staff to get an overview of the whole hospital state as well as the emergency department condition.

Objectives revisited

We now want to come back on our objectives that we defined in section 4.3 and explain how we met them in our project.

1. *Discover where the wait times are the highest.* The visualization tool permits to detect possible high wait times with statical information displayed on the screen and the data simulated by our simulation model can be analyzed to point such information out.

2. *Discover potential bottlenecks.* The visualization tool can read the patient data and directly show that, at some point of the overall process, there are too much patients waiting for receiving care.

3. *Explain the reasons behind high wait times and their impact on the quality of care.* The simulated data provide us with information about high wait times and then, we can analyze the other metrics in the other parts of the model to discover that this triggers a snowball effect on the overall quality of care.

4. *Discover which factors contribute to what kinds of delays.* As above, our simulated data give us precious information to discover that, for instance, when there is only one physician in the emergency department, the time to PIA will be higher for the patients.

5. *Test and analyze hypothesis to understand why and/or how a phenomenon occurs.* Our simulation model has been developed to be easily parameterized and therefore, if we add or remove resources at some point of the model to see if it will have an impact is very easy to do.

6. *Perform what-if analysis and offer a feedback of new policies that might be implemented (Decision Support).* Althought our simulation model can be improved, it is mature enough to already design what-if questions and trying to answer it.

Although we do not have a direct impact on reducing the high wait times, we were able to develop two tools which provides some precious information and statitics about the trends of the patient flow. The simulation model and the visualization tool are intended to be used by the managers of the hospital. Therefore, the results can be proceeded and then transmitted to the medical staff in order to improve their way to take care of the patients.

7.3 Perspectives

We identified some perspectives of the developed tools in their respective sections. We will recall the major ones and add some ideas about a combination of the simulation and the visualization tool.

Simulation model

Despite all the work already allocated to the **arrival process**, it could also be improved by modeling specific distributions for long weekends and holidays in Canada which tend to be subject to increased patients arrivals.

Another interesting improvement would be to implement the **Canadian Surgical Program**. Surgeons have complete freedom on which operations they want to proceed and it is current for them to arbitrarily change the schedule of the operations and to decide to proceed a more remunerative one. This behavior pushes the delays for other patients waiting for a classical operation. Therefore, investigating the consequences of such decisions would be a nice application for our simulation model.

The last future work we recall here is to get **real numbers about the tests**. We think that it would be nice to take into account the CTAS level and to implement a dynamic percentages adaption to the previous tests taken. We think this should make our simulation closer to the reality.

Visualization tool

The perspectives we find important for the visualization tool are the **real-time information visualization** and the **statistical information enrichment**.

For the first one, having to possibility to link the visualization software with a *RFID system* would greatly increase the responsiveness but also detect overcrowding problems more quickly.

The second improvement that can be made is to add more statistical information. In the way of a decision support tool, the management staff needs a lot of statistical information in order to take decisions in the way the hospital is handled.

Both combined

In addition to the future work related to the visualization and the simulation tools, we add some ideas about a potential combination of both tools.

An abstract solution consists in the integration of the simulation model into the visualization tool. The user could then be allowed to directly launch the simulation and get the results through the visualization software.

In contrast, another nice feature would be to generate a visualization tool right from the simulation model. And we could add this feature into the *Arena* software itself. This feature would preserve the data semantics to be able to conserve the link with the data sources using a language specially developed for our needs.

Furthermore, we performed some analysis on the data received from the RVHS. Performing a *complete* Reverse Engineering on these data in order to find how to improve the performance using the data-architecture tool DB-MAIN[1] could be interesting.

Finally, patient flow information such as the typical process of a patient having a heart attack could be obtained and used to improve our models but also to catch or infer the characteristic path followed by such patients. These information would be very useful for the staff to slowly make the process of care automatic.

7.4 Lessons learned

The first thing we learned is the particular context of the Canadian health care system and emergency departments. This domain is full of interesting cases to study and we hope that we have put our shoulders to the wheel.

[1] `http://www.db-main.eu/`

Through this project, we have been lucky to work with true clients who provided us with real data. This was an opportunity for us to learn how to tackle with real stakeholders.
However, we also learned that the reality is sometimes far away from what we learned at the university. Indeed, we had to deal with data quality issues and a lack of disponibility of our partners that slowed our development down.

Besides that, we learned how to conduct a simulation project and to use the powerful Arena software. Furthermore, we learned how to present to a decision maker the most important metrics of a domain. Now, we know that managing an emergency department, a system with lots of parameters and things to consider, is a very challenging work.

Finally, we learned how to prepare a scientific poster and how to present it during a big event such as CASCON.

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Appendix A

Simulation results conceptual schema

Figure A.1[1] has already been introduced in subsection 6.1.4. We now detail the schema and recall that the time unit is in minutes.

A.1 Patient record

- `Patient_ID`: unique number attributed to a patient.
- `Time_In`: time when the patient arrived in the emergency department.
- `Inter_Arrival_Time`: time elapsed between the last patient `Time_In` and the current `Time_In`.
- `Registration_Time`: time before to be registered.
- `Registration_Queue`: the number of patient in the registration queue when the patient enters into it.
- `Registration_Duration`: registration duration.
- `Triage_Time`: time before to be triaged.
- `Triage_Queue`: the number of patient in the triage queue when the patient enters into it.
- `Triage_Duration`: triage duration.
- `CTAS`: CTAS level of the patient.
- `Ambulance`: '1' for an ambulance arrival, '0' otherwise.
- `Time_to_PIA`: time elapsed between the arrival time and the moment the patient is assessd by a physician for the first time.
- `PIA_Duration`: duration of the Physician Initial Assessment.

[1] This schema has been made using the data-architecture tool, DB-MAIN (`http://db-main.eu/`).

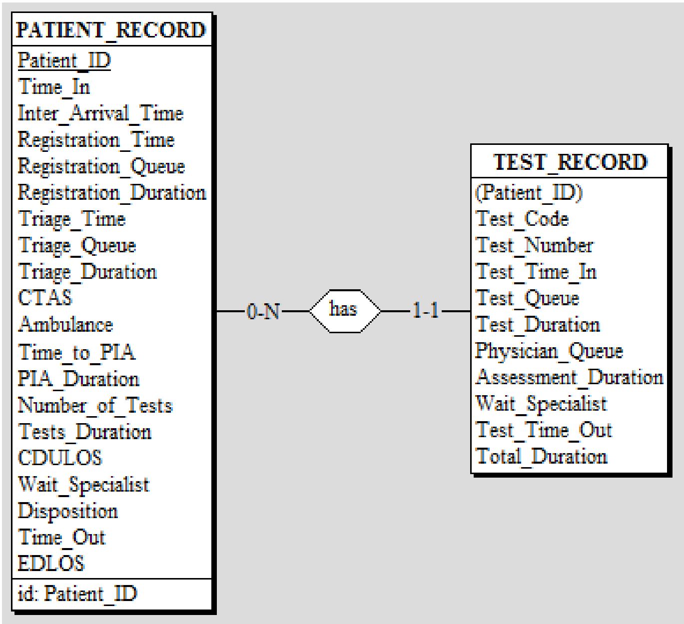

Figure A.1: Simulation results conceptual schema

- `Number_of_Tests`: number of tests the patient passed.
- `CDULOS`: time passed in the CDU.
- `Wait_Specialist`: time spent wainting the specialist.
- `Disposition`: '1' for LWBS, '2' for discharged and '3' for admitted.
- `Time_Out`: time when the patient leaves the emergency department.
- `EDLOS`: time elapsed between the patient's arrival and the patient's departure.

A.2 Test record

- `(Patient_ID)`: the identifier of the patient who has passed the test.
- `Test_Code`: '1' for urine sample, '2' for blood test, '3' for electrocardiogram, '4' for CT scan, '5' for X-ray and '6' for MRI.
- `Test_Number`: number representing the x-th tests for the patient.
- `Test_Time_In`: time before to pass the test.
- `Test_Queue`: the number of patient in the test queue when the patient enters into it.
- `Test_Duration`: test duration.

- `Physician_Queue`: the number of patient in the physician queue when the patient enters into it.
- `Assessment_Duration`: assessment duration.
- `Wait_Specialist`: time spent wainting the specialist.
- `Test_Time_Out`: time when the test, the assessment and the specialist consultation are finished.
- `Total_Duration`: total duration of the test (test + assessment + specialist).

Appendix B

Simulation results

```
==================
 PATIENTS RECORDS
==================

GENERAL | 41983.0
-------
Ambulance arrivals: 3621.0 (8.62492%)
Walk-In arrivals: 38362.0 (91.375084%)
LWBS: 255.0 (0.6073887%)
Admitted: 2490.0 (5.930972%)
Discharged: 39238.0 (93.46164%)
Average registration duration: 5.073244
Average registration queue: 0.0017864374
Average triage duration: 10.083796
Average triage queue: 0.004215992
Min PIA duration: 20.0
Average PIA duration: 73.729294
Max PIA duration: 503.51434
Min #tests: 0.0
Average #tests: 0.9122651
Max #tests: 10.0
Min tests duration: 0.0
Average tests duration: 118.217255
Max tests duration: 2835.6265
Min wait specialist: 0.01008703
Average wait specialist: 68.76663
Max wait specialist: 180.0
Min EDLOS: 15.0
Average EDLOS: 210.03542
Max EDLOS: 2875.2249
CDU admissions: 1097.0 (2.6129625%)
Min CDULOS: 10.0
Average CDULOS: 466.1607
Max CDULOS: 1440.0
```

```
Min wait MED bed time: 10.010087
Average wait MED bed time: 78.76667
Max wait MED bed time: 190.0
Min MED duration: -9.7212505E-5
Average MED duration: 8.675864
Max MED duration: 63.7294
Average #patient in ED (any time): 23.81427

CTAS 1 | 140.0 (0.33346832%)
------
Ambulance arrivals: 63.0 (45.0%)
Walk-In arrivals: 77.0 (55.0%)
LWBS: 0.0 (0.0%)
Admitted: 51.0 (36.42857%)
Discharged: 89.0 (63.57143%)
Average registration duration: 5.1
Average registration queue: 0.0
Average triage duration: 10.107142
Average triage queue: 0.0
Min PIA duration: 20.0
Average PIA duration: 23.067553
Max PIA duration: 29.866852
Min #tests: 1.0
Average #tests: 3.4285715
Max #tests: 9.0
Min tests duration: 26.5
Average tests duration: 452.84662
Max tests duration: 1417.0
Min wait specialist: 1.7596258
Average wait specialist: 67.052185
Max wait specialist: 180.0
Min EDLOS: 65.27888
Average EDLOS: 494.91904
Max EDLOS: 1457.5015
CDU admissions: 7.0 (5.0%)
Min CDULOS: 54.530216
Average CDULOS: 541.98926
Max CDULOS: 895.1949
Min wait MED bed time: 11.759625
Average wait MED bed time: 77.052185
Max wait MED bed time: 190.0
Min MED duration: 0.06240718
Average MED duration: 8.223295
Max MED duration: 60.825966

CTAS 2 | 4709.0 (11.216445%)
------
Ambulance arrivals: 849.0 (18.029306%)
Walk-In arrivals: 3860.0 (81.970695%)
LWBS: 5.0 (0.106179655%)
```

```
Admitted: 676.0 (14.35549%)
Discharged: 4028.0 (85.53833%)
Average registration duration: 5.065831
Average registration queue: 0.0016988745
Average triage duration: 10.080059
Average triage queue: 0.0046719047
Min PIA duration: 20.0
Average PIA duration: 22.830502
Max PIA duration: 32.375942
Min #tests: 1.0
Average #tests: 3.6124575
Max #tests: 10.0
Min tests duration: 26.5
Average tests duration: 474.96948
Max tests duration: 2835.6265
Min wait specialist: 0.27633226
Average wait specialist: 66.408936
Max wait specialist: 180.0
Min EDLOS: 15.0
Average EDLOS: 515.7924
Max EDLOS: 2875.2249
CDU admissions: 155.0 (3.2915692%)
Min CDULOS: 10.0
Average CDULOS: 442.90494
Max CDULOS: 1440.0
Min wait MED bed time: 10.276332
Average wait MED bed time: 76.40892
Max wait MED bed time: 190.0
Min MED duration: 0.012410188
Average MED duration: 8.492282
Max MED duration: 49.374138

CTAS 3 | 20536.0 (48.915035%)
------
Ambulance arrivals: 2074.0 (10.099338%)
Walk-In arrivals: 18462.0 (89.900665%)
LWBS: 148.0 (0.7206856%)
Admitted: 1523.0 (7.4162445%)
Discharged: 18865.0 (91.86307%)
Average registration duration: 5.0763535
Average registration queue: 0.001996494
Average triage duration: 10.0826845
Average triage queue: 0.0048208027
Min PIA duration: 20.0
Average PIA duration: 80.79753
Max PIA duration: 503.51434
Min #tests: 0.0
Average #tests: 0.7488228
Max #tests: 5.0
Min tests duration: 0.0
```

```
Average tests duration: 96.26867
Max tests duration: 1784.0
Min wait specialist: 0.046105027
Average wait specialist: 69.980644
Max wait specialist: 180.0
Min EDLOS: 15.0
Average EDLOS: 195.19318
Max EDLOS: 2055.1028
CDU admissions: 667.0 (3.2479548%)
Min CDULOS: 10.0
Average CDULOS: 524.80365
Max CDULOS: 1440.0
Min wait MED bed time: 10.046105
Average wait MED bed time: 79.98067
Max wait MED bed time: 190.0
Min MED duration: -9.7212505E-5
Average MED duration: 8.741352
Max MED duration: 63.7294

CTAS 4 | 14752.0 (35.13803%)
------
Ambulance arrivals: 584.0 (3.9587853%)
Walk-In arrivals: 14168.0 (96.041214%)
LWBS: 101.0 (0.6846529%)
Admitted: 224.0 (1.5184382%)
Discharged: 14427.0 (97.796906%)
Average registration duration: 5.07199
Average registration queue: 0.0013557484
Average triage duration: 10.086836
Average triage queue: 0.0033893709
Min PIA duration: 20.0
Average PIA duration: 79.90292
Max PIA duration: 502.63074
Min #tests: 0.0
Average #tests: 0.35130706
Max #tests: 3.0
Min tests duration: 0.0
Average tests duration: 44.462574
Max tests duration: 882.5
Min wait specialist: 0.01008703
Average wait specialist: 68.39412
Max wait specialist: 180.0
Min EDLOS: 15.0
Average EDLOS: 142.82056
Max EDLOS: 1218.8165
CDU admissions: 260.0 (1.7624729%)
Min CDULOS: 10.0
Average CDULOS: 334.92624
Max CDULOS: 1440.0
Min wait MED bed time: 10.010087
```

```
Average wait MED bed time: 78.39409
Max wait MED bed time: 190.0
Min MED duration: 0.06700999
Average MED duration: 9.19163
Max MED duration: 61.00568

CTAS 5 | 1846.0 (4.397018%)
------
Ambulance arrivals: 51.0 (2.7627301%)
Walk-In arrivals: 1795.0 (97.23727%)
LWBS: 1.0 (0.054171182%)
Admitted: 16.0 (0.8667389%)
Discharged: 1829.0 (99.07909%)
Average registration duration: 5.065547
Average registration queue: 0.0032502708
Average triage duration: 10.079632
Average triage queue: 0.0032502708
Min PIA duration: 20.0
Average PIA duration: 80.22607
Max PIA duration: 482.2643
Min #tests: 0.0
Average #tests: 0.09756097
Max #tests: 1.0
Min tests duration: 0.0
Average tests duration: 11.470608
Max tests duration: 380.0701
Min wait specialist: 5.3618164
Average wait specialist: 63.50805
Max wait specialist: 180.0
Min EDLOS: 15.0
Average EDLOS: 110.72872
Max EDLOS: 659.6531
CDU admissions: 8.0 (0.43336946%)
Min CDULOS: 33.851166
Average CDULOS: 226.18831
Max CDULOS: 387.02585
Min wait MED bed time: 15.361816
Average wait MED bed time: 73.50804
Max wait MED bed time: 190.0
Min MED duration: 0.558765
Average MED duration: 4.420637
Max MED duration: 11.93572


==============
 TEST RECORDS
==============

GENERAL | 38934.0
-------
```

```
Min queue for test: 0.0
Average queue for test: 1.0273797E-4
Max queue for test: 2.0
Min test duration: 20.0
Average test duration: 20.005318
Max test duration: 26.561117
Min queue for physician: 0.0
Average queue for physician: 1.4383572
Max queue for physician: 15.0
Min assessment duration: 6.5
Average assessment duration: 75.40951
Max assessment duration: 500.65082
Min wait specialist: 0.0
Average wait specialist: 35.145683
Max wait specialist: 180.0
Min total duration: 26.5
Average total duration: 130.5602
Max total duration: 673.7228

URINE SAMPLE | 6934.0 (17.809626%)
------------
Min queue for test: 0.0
Average queue for test: 0.0
Max queue for test: 0.0
Min test duration: 20.0
Average test duration: 20.006426
Max test duration: 26.125954
Min queue for physician: 0.0
Average queue for physician: 1.1576291
Max queue for physician: 11.0
Min assessment duration: 6.5
Average assessment duration: 76.926216
Max assessment duration: 500.65082
Min wait specialist: 0.0
Average wait specialist: 0.0
Max wait specialist: 0.0
Min total duration: 26.5
Average total duration: 96.932625
Max total duration: 520.6508

BLOOD TEST | 12057.0 (30.967793%)
----------
Min queue for test: 0.0
Average queue for test: 2.488181E-4
Max queue for test: 2.0
Min test duration: 20.0
Average test duration: 20.005592
Max test duration: 26.561117
Min queue for physician: 0.0
Average queue for physician: 1.9598573
```

```
Max queue for physician: 15.0
Min assessment duration: 6.5
Average assessment duration: 76.014656
Max assessment duration: 498.93716
Min wait specialist: 0.0
Average wait specialist: 0.0
Max wait specialist: 0.0
Min total duration: 26.5
Average total duration: 96.02028
Max total duration: 518.93713

ELECTROCARDIOGRAM | 5049.0 (12.9681%)
-----------------
Min queue for test: 0.0
Average queue for test: 0.0
Max queue for test: 0.0
Min test duration: 20.0
Average test duration: 20.004606
Max test duration: 24.277206
Min queue for physician: 0.0
Average queue for physician: 0.83026344
Max queue for physician: 7.0
Min assessment duration: 6.5
Average assessment duration: 75.55577
Max assessment duration: 490.5
Min wait specialist: 0.040850636
Average wait specialist: 69.10547
Max wait specialist: 180.0
Min total duration: 27.793552
Average total duration: 164.6662
Max total duration: 555.5

CT SCAN | 4243.0 (10.89793%)
-------
Min queue for test: 0.0
Average queue for test: 0.0
Max queue for test: 0.0
Min test duration: 20.0
Average test duration: 20.00587
Max test duration: 24.13468
Min queue for physician: 0.0
Average queue for physician: 0.6846571
Max queue for physician: 7.0
Min assessment duration: 6.5
Average assessment duration: 74.5022
Max assessment duration: 488.06284
Min wait specialist: 0.0032670337
Average wait specialist: 69.24586
Max wait specialist: 180.0
Min total duration: 27.629623
```

```
Average total duration: 163.75406
Max total duration: 673.7228

X-RAY | 10447.0 (26.832588%)
-----
Min queue for test: 0.0
Average queue for test: 9.572126E-5
Max queue for test: 1.0
Min test duration: 20.0
Average test duration: 20.004372
Max test duration: 23.743265
Min queue for physician: 0.0
Average queue for physician: 1.6502345
Max queue for physician: 13.0
Min assessment duration: 6.5
Average assessment duration: 73.81239
Max assessment duration: 498.6942
Min wait specialist: 0.0050910627
Average wait specialist: 68.134766
Max wait specialist: 180.0
Min total duration: 26.870815
Average total duration: 161.95131
Max total duration: 615.48926

MRI | 204.0 (0.52396363%)
---
Min queue for test: 0.0
Average queue for test: 0.0
Max queue for test: 0.0
Min test duration: 20.0
Average test duration: 20.005724
Max test duration: 21.167604
Min queue for physician: 0.0
Average queue for physician: 0.034313727
Max queue for physician: 1.0
Min assessment duration: 6.5
Average assessment duration: 85.07516
Max assessment duration: 394.93716
Min wait specialist: 0.04337547
Average wait specialist: 67.824326
Max wait specialist: 180.0
Min total duration: 31.02045
Average total duration: 172.9052
Max total duration: 509.66425

CTAS 1 | 511.0 (1.3124775%)
------
Min queue for test: 0.0
Average queue for test: 0.0
Max queue for test: 0.0
```

```
Min test duration: 20.0
Average test duration: 20.012114
Max test duration: 22.888815
Min queue for physician: 0.0
Average queue for physician: 1.5127201
Max queue for physician: 9.0
Min assessment duration: 6.5
Average assessment duration: 80.046
Max assessment duration: 395.0
Min wait specialist: 0.0
Average wait specialist: 33.942272
Max wait specialist: 180.0
Min total duration: 26.5
Average total duration: 134.00043
Max total duration: 434.7313

CTAS 2 | 17572.0 (45.13279%)
------
Min queue for test: 0.0
Average queue for test: 1.7072615E-4
Max queue for test: 2.0
Min test duration: 20.0
Average test duration: 20.006031
Max test duration: 26.561117
Min queue for physician: 0.0
Average queue for physician: 1.4918052
Max queue for physician: 15.0
Min assessment duration: 6.5
Average assessment duration: 77.58202
Max assessment duration: 500.65082
Min wait specialist: 0.0
Average wait specialist: 35.224777
Max wait specialist: 180.0
Min total duration: 26.5
Average total duration: 132.81297
Max total duration: 667.5

CTAS 3 | 15498.0 (39.805824%)
------
Min queue for test: 0.0
Average queue for test: 6.452446E-5
Max queue for test: 1.0
Min test duration: 20.0
Average test duration: 20.003796
Max test duration: 24.13468
Min queue for physician: 0.0
Average queue for physician: 1.4126339
Max queue for physician: 14.0
Min assessment duration: 6.5
Average assessment duration: 74.26349
```

```
Max assessment duration: 490.2693
Min wait specialist: 0.0
Average wait specialist: 35.048862
Max wait specialist: 180.0
Min total duration: 26.5
Average total duration: 129.31586
Max total duration: 562.4124

CTAS 4 | 5172.0 (13.284019%)
------
Min queue for test: 0.0
Average queue for test: 0.0
Max queue for test: 0.0
Min test duration: 20.0
Average test duration: 20.006905
Max test duration: 26.125954
Min queue for physician: 0.0
Average queue for physician: 1.3354602
Max queue for physician: 12.0
Min assessment duration: 6.5
Average assessment duration: 71.26578
Max assessment duration: 498.93716
Min wait specialist: 0.0
Average wait specialist: 35.483807
Max wait specialist: 180.0
Min total duration: 26.5
Average total duration: 126.75631
Max total duration: 673.7228

CTAS 5 | 181.0 (0.4648893%)
------
Min queue for test: 0.0
Average queue for test: 0.0
Max queue for test: 0.0
Min test duration: 20.0
Average test duration: 20.00136
Max test duration: 20.246086
Min queue for physician: 0.0
Average queue for physician: 1.1823205
Max queue for physician: 8.0
Min assessment duration: 6.5
Average assessment duration: 67.87343
Max assessment duration: 354.75842
Min wait specialist: 0.0
Average wait specialist: 29.507944
Max wait specialist: 180.0
Min total duration: 26.5
Average total duration: 117.38271
Max total duration: 380.0701
```

Appendix C

RVHS database explanations

Here is the documentation we received from the CIO of the RVHS, our partner in this project. This documentation concerns the real data provided.

`EDVisit` Table C.1 concerns the emergency department.

`[FacilityID] [char](3) NOT NULL,`	– 002
`[Date] [char](8) NOT NULL,`	– Date of ED Visit
`[URN] [varchar](8) NOT NULL,`	– Unique Patient Number
`[Account] [varchar](10) NOT NULL,`	– unique visit ID
`[TriaDate] [varchar](8) NULL,`	– triage date
`[CTAS] [varchar](8) NULL,`	– acuity level
`[LWBS] [int] NULL,`	– left without being seen 0/1
`[Diagnosis] [varchar](50) NULL,`	– patient complaint,not Drs diag.
`[Disposition] [varchar](50) NULL,`	– D:discharge, A:Admit
`[Admitted] [int] NULL,`	– 1 if admitted, 0 otherwise
`[TriageDtTm] [datetime] NULL,`	– Triage datetime
`[AmbArrDtTm] [datetime] NULL,`	– ambulance arrival
`[TransferOfCareDtTm] [datetime] NULL,`	– transfer or care (ambul.)
`[DepartDtTm] [datetime] NULL,`	– depart ED
`[LeftErDtTm] [datetime] NULL,`	– actual time to leave ED
`[AdmDtTm] [datetime] NULL,`	– admittion datetime, if admitted
`[CDUDtTm] [datetime] NULL,`	– CDU in time
`[Ambulance_OT] [real] NULL,`	– ambulance offload tm in mins
`[LOSTriageToCDU] [real] NULL,`	– length of stay, triage to CDU
`[LOSCDUtoLeftER] [real] NULL,`	– LOS CDU to Left ED, in mins
`[LOSTriageToLeftER] [real] NULL,`	– LOS Triage to Left ED, in mins
`[LOS] [real] NULL,`	– LOS at ED (minus CDU), in mins
`[ImportDate] [datetime] NULL`	– not important

Table C.1: `edvisit` table

`InPatientVisits` Table C.2 contains inpatient records only for MEDicine and SURgical services. Also includes ALC. ALC is recorded as service but it is not a clinical service, it is status of the patient. A patient is declared ALC when s/he finishes treatment at a given service level and requires lower level services but due to unavailability occupies a higher service level bed. For example a MED patient can become an ALC patient occupying a Medicine bed while she waits to be transferred to next level. Note in this table the ALC records are not only those that are linked to Medicine and Surgical beds, but also those in other units such as Complex Continuing Care, etc.

`[FacilityID] [varchar](3) NULL,`	
`[UnitNumber] [char](8) NOT NULL,`	– unique patient number
`[AcctNumber] [char](10) NOT NULL,`	– unique visit number
`[Service] [varchar](12) NULL,`	– service MED/SUG plus ALC
`[Location] [varchar](12) NULL,`	– physical ward
`[AdmitDt] [varchar](8) NULL,`	– admit date
`[DischargeDtTm] [date] NULL,`	– discharge date
`[DischBef11] [int] NULL,`	– discharged before 1100 hrs
`[DischBef14] [int] NULL,`	– discharged before 1400 hrs
`[LOS] [int] NULL,`	– length of stay
`[ImportDate] [datetime] NULL`	– ignore

Table C.2: `inpatientvisits` table

`IPCensus` Table C.3 contains a record per patient day.

`[FacilityID] [varchar](3) NULL,`	–
`[AcctNumber] [varchar](10) NOT NULL,`	– visit number
`[AdmitDt] [varchar](8) NULL,`	– admit date
`[LOS] [real] NULL,`	– from admit to census date
`[CensusDt] [varchar](8) NOT NULL,`	– census date
`[UnitNumber] [varchar](8) NULL,`	– unique patient number
`[Location] [varchar](12) NULL,`	– location (ward)
`[Bed] [varchar](12) NULL,`	– bed
`[ELOS] [real] NULL`	– expected length of stay

Table C.3: `ipcensus` table

`ALC` Table C.4 contains one record per each patient ALC day.

The account (or visit) number changes by the visit. A patient P who has come to ED has account A1, and s/he is admitted s/he will be assigned account A2. The two visits (A1$\rightarrow$A2) create an "episode" of care. If patient P turns to ALC, the account number does not change.

`[CensusDtTm] [datetime] NOT NULL,`	– census date
`[FacilityID] [varchar](3) NULL,`	
`[Location] [varchar](10) NULL,`	
`[UnitNumber] [varchar](8) NULL,`	
`[AcctNumber] [varchar](10) NOT NULL,`	
`[AdmitDate] [varchar](8) NULL,`	
`[ALCDate] [varchar](8) NULL,`	– date the patient declared ALC
`[ImportDate] [datetime] NULL`	

Table C.4: `alc` table

Appendix D

Cascon poster

For our participation at the IBM Cascon 2011[1] conference in Toronto, we provided a poster about our work. This one was accepted and presented at the conference.

[1] https://www-927.ibm.com/ibm/cas/cascon/

FlowER

Simulation and Visualization of Patient Flows in a Hospital Emergency Department

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Abstract

The health care system in Canada and abroad is under increasing pressure to become more efficient. Hospital emergency departments (ED) across the country are under pressure because of the high volume of patients that go the emergency for medical attention. The wait times that patients spend in ED is a serious concern of the public and a problem that health authorities straggle to address.

How can this situation be improved? There is a strong indication that better access to relevant information and *better coordination of existing resources and actors would significantly increase the efficiency of hospital EDs*. Existing Health Information Technology Applications do not match the patient journey through the system, and existing processes are designed to meet the provider rather than the patient needs. The objective of this project is through data mining, data visualization and simulation, to analyze and reengineer processes and systems to become more patient-centric.

This project is conducted in a *partnership between two Universities and Rouge Valley Health Systems*, which operates two hospitals in the Greater Toronto Area. Realistic hospital patient flow data and ED workloads are used to understand the patterns of hospital flow, test assumptions and eventually validate our methods. Access to realistic use cases and data is essential for the development of methods and deriving results that are applicable to other similar environments.

Objective 1: *Understand* emergency rooms behavior

The time patients spent in EDs can increase due to many reasons. It is necessary to know when people access emergency department services and what for, deeply understand the reason why they stay in EDs longer and which factors contribute to what kinds of delays. [1]

The facts are:

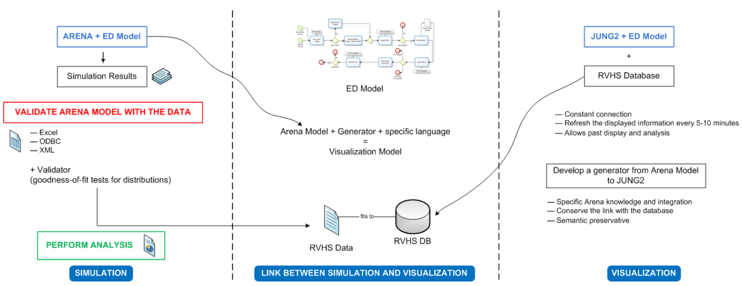
- "Most of ED visits are for less urgent conditions (for example, chronic back pain or minor allergic reactions) or non-urgent conditions (for example, sore throat or menses) based on the Canadian Triage and Acuity Scale (CTAS)." [1]
- CTAS level I and II are assessed in priority compared to other patients.
- Peak times—period during which the number of arrival is significantly higher than normal—exist and must be considered (for example, more patients on Monday, or Friday because of partying).
- Special examination (X-rays), specialist assessment or waiting for an available bed (sometimes longer than 24 hours [2]) can significantly impact the wait time considering the unavailability of resources.

First conclusion : "ED overcrowding is a complex, system-wide problem, with no single factor to explain why it occurs, and no single solution." [2]

What is needed:

- A generic and a specific model of the ED.
- Streamlined clinical pathways with expected performance targets especially with respect of length of stay in ED (for example, heart attack pathway).
- The number of patients coming and the reason for their visit.
- What are the resources and what is their schedule or usage percentage.
- Understand their behavior, decisions, needs and obligations of the care team.
- Discover where the wait times are the highest.
- Explain the reasons behind high wait times and their impact on the quality of care.

Methodology overview



Future Works

- Perform Reverse Engineering on the database in order to find how to improve the performance using the data-architecture tool: DB-MAIN. [5]
- 3D and closer to the reality simulation model.

References

[1] Canadian Institute for Health Information, *Understanding Emergency Department Wait Times: Who Is Using Emergency Departments and How Long Are They Waiting?* (Ottawa: CIHI, 2005)

[2] Canadian Institute for Health Information, *Understanding Emergency Department Wait Times: Access to Inpatient Beds and Patient Flow* (Ottawa: CIHI, 2007)

[3] http://www.arenasimulation.com/

[4] http://jung.sourceforge.net/

[5] http://www.db-main.eu/

Objective 2: *Discover and validate* efficient patient flows

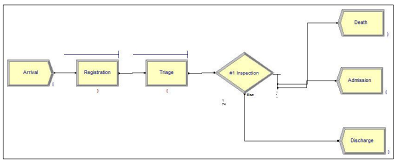
Patients progressing through the different stages in the hospital, from admission to discharge, leave data trails in different operational information systems. These data trails can be mined in order to reconstruct the patients' flows, evaluate their efficiency and discover context-based alternative flows. Hospitals gather and maintain large amounts of historical data. We will apply and extend data mining and knowledge discovery algorithms to extract and evaluate patient flows.

Solution view 1: *Simulation* with Arena

"Arena simulation software helps protect your business by analyzing the impact of new, "what-if" business ideas, rules, and strategies before implementation on live customers—offline, without causing disruptions in service." [4]

Advantages of using simulations:

- Adapted based on individual context and system attributes.
- All the patient flow process can be simulated including nurses and physician schedules, equipment (X-rays, etc), rooms,…
- Running the simulation can show us great value knowledge to improve the patient flow and decrease the wait times.
- Hypothesis can be tested and analyzed to understand why and/or how a phenomenon occurs.
- The animation is a real-time visualization tool permitting to control the time speed and see what happens deeply. The simulation shows how the system works in reality and not how it is supposed to.
- Bottlenecks can be discovered.
- What-if analysis is easy to perform and offers directly a feedback of new policies that might be implemented (*Decision Support*).



The goal of this solution view is to study the resources configuration and utilization and find the optimal way to use these resources by analyzing the results to avoid bottleneck and reduce the wait times by improving the process policies.

Solution view 2: *Visualization* with graphs

The main idea is to avoid the classical "static" view of the market dashboard and make a more realistic and dynamic view of the EDs.

The motivation is to build a visualization tool useful for business and top chief managers, but also for physicians and nurses.

In order to satisfy both sides, the main view of the department is based on a graph built with JUNG2. [4]

Under each node, some basic information will be displayed. This gives a quick overview of possible congestion problems, waiting time peaks,…

If a complement of data is needed, a basic charts can be displayed by clicking on a specific node.

Solution view 3: *Bind* the Simulation with the Visualization

In order to keep the simulation model synchronized with the visualization model itself connected to our data sources, a tool is under development to:

- Transfer 100% of the simulation model to the visualization.
- Keep the relevant patient states corresponding of the data.
- Perform the generation of the model code.
- Be integrated directly into Arena.
- Preserve the data semantic to be able to conserve the link with the data sources using a language specially developed for our specific needs.